VOL. 5 JANUARY, 1918 No. 1

SOIL SCIENCE

FOUNDED BY

RUTGERS COLLEGE

NEW BRUNSWICK, N. J.

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PUBLISHED MONTHLY BY
WILLIAMS & WILKINS COMPANY
BALTIMORE, MD., U. S. A.

THE CAMBRIDGE UNIVERSITY PRESS
FETTER LANE, LONDON, E. C.

Entered as second-class matter August 23, 1917, at the post office at Baltimore, Maryland, under the act of March, 3, 1879

SOIL SCIENCE

Contents for January, 1918

SOME AVAILABILITY STUDIES WITH AMMONIUM PHOSPHATE AND ITS CHEMICAL AND BIOLOGICAL EFFECTS UPON THE SOIL[1]

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Received for publication July 15, 1917

INTRODUCTION

The purpose in beginning the work which is reported on the following pages was to make a study of the availability and the effect on germination and biological activities of an ammonium phosphate fertilizer manufactured by the American Cyanamid Company. In the preparation of this fertilizer ground phosphate rock is mixed with sufficient sulfuric acid to convert the phosphorus compounds into free phosphoric acid, and the latter removed from the mixture by filtration and washing the residue. Ammonia is produced in gaseous form by steaming crude calcium cyanamid in an autoclave under a pressure of several atmospheres. The ammonia is bubbled into the phosphoric acid until it is converted chiefly into di-ammonium phosphate but at the same time some citrate-insoluble iron and aluminum ammonium phosphates are formed. With methyl orange as an indicator, phosphoric acid is then added until the solution reaches the proportions of mono-ammonium phosphate, the insoluble phosphates being thereby rendered available. The solution after evaporation to dryness is known commercially as "Ammo-Phos." It is a light gray material resembling acid-phosphate in appearance.

A large amount of work has been done with ammonium sulfate, and its relative value as compared with other common nitrogenous fertilizers determined, but for the most part other ammonium salts have received little consideration. Ammonium phosphate, for example, has been omitted from fertilizer studies because it has been considered too expensive to be worthy of consideration as a fertilizer. Now that a satisfactory method has been developed for its manufacture, it is highly important that we know under just what conditions this new fertilizer will give the best results and how much may be safely and economically applied to various crops. Does the ammonia act like that in ammonium sulfate and the phosphorus like that in acid phosphate, as we might expect, or does the combining of the two radicals change their efficiency or chemical effects to any extent? Both the acid and basic

[1] A portion of a thesis submitted to the faculty of Rutgers College in partial fulfillment of the requirements for the degree of Doctor of Philosophy, 1917.

radicals are utilized as foods for plants and for this reason, if no other, we should expect that the effects would be somewhat different, especially after long continued use.

HISTORICAL

Ammonium phosphate was used by several of the early investigators in their studies on the nutrition of plants. These various workers observed that ammonium salts often failed to nourish certain plants as they should, and sought after the reasons for their negative results and the conditions under which ammonium salts could be profitably used. A few investigators have worked on the chemical and biological effects produced by an application of ammonium phosphate to a soil. The effect on germination and young plants has been reported in a few cases. For the most part, though, ammonium phosphate has received little consideration as a possible fertilizer. The work noted by the writer is briefly abstracted below.

Johnson (11) reports the work of Ville who grew wheat in calcined sand, to which was added 0.11 gm. of nitrogen in each case, either in the form of potassium nitrate, ammonium chloride, ammonium nitrate or ammonium phosphate. The results were as follows:

SOURCE OF NITROGEN	STRAW AND ROOTS	GRAIN	AVERAGE CROP	NITROGEN IN CROP
Potassium nitrate	20.70 19.22	6.20 7.30	26.71	0.221
Ammonium chloride	15.10 17.34	4.93 3.54	18.83	0.142
Ammonium nitrate	12.20 14.87	3.72 5.86	18.32	0.133
Ammonium phosphate	12.96 15.82	3.77 4.34	18.40	0.133

It is seen that all the ammonium salts gave about the same results, the crop being about one-fourth less than with potassium nitrate. However, no allowance was made for the potassium in the potassium nitrate.

Hellriegel (11) obtained a larger yield of clover with ammonium sulfate and ammonium phosphate than with ammonium nitrate or sodium nitrate.

Birner and Lucanus (11), in 1864, found that in water cultures sulfate and phosphate of ammonia did not effectively replace nitrates.

Hampe (11), in 1866, using ammonium phosphate and keeping the solution faintly acid, obtained a corn plant with a dry weight of 18 gm. and having 36 perfect seeds. The solution did not contain any nitrates.

Kühn (11), in 1866, grew two small corn plants, one with ammonium phosphate and the other with ammonium sulfate as the only sources of nitrogen. The experiments were interrupted by the high temperature in the greenhouse.

Wagner (11), in 1868, found in agreement with the work of Hampe of the

previous year that a maize seedling, after growing for 2 weeks in an artificial soil grew normally when placed in a nutritive solution containing ammonium phosphate as a source of nitrogen. One plant, when dried, weighed 26.5 gm. and carried 48 ripe seeds.

Claudel and J. Cochetelle (3) found that basic phosphates, including ammonium phosphate, are favorable to germination and especially to leguminous seeds. Potassium salts, ammonium sulfate, sodium nitrate and superphosphate were injurious to germination, especially to lentils, lucerne and flax. Wheat was quite resistant.

Tanret (33), using nutrient solutions containing an excess of either ammonium nitrate, ammonium sulfate or ammonium chloride for the culture of *Aspergillus niger* found that no spores were produced during the first month of growth. On the other hand, ammonium phosphate favored spore production.

Steffeck and Maercker (32), using ammonium phosphate as a nitrogenous manure, found that it acted in a manner similar to ammonium sulfate with both oats and barley, both as regards the yield and nitrogen content of the grain. As a phosphate fertilizer the ammonium phosphate yielded only 88.33 per cent as much as acid phosphate soluble in water.

Hall and Gimingham (6) shook soil for 24 hours with a solution of ammonium salts and determined whether there was an increase in acidity or evolution of ammonia. Sand gave negative results. Clay showed no change in acidity or withdrawal of the acid radical from solution. Complete absorption of the base did not occur in clay with ammonium chloride, ammonium carbonate or ammonium phosphate. In the case of the latter two salts some of the acid was removed from solution.

Pantanelli and Severini (27), growing wheat, mustard, corn, flax and rice in water cultures, found that a rapid absorption of the ammonium cation increases the acidity of the nutritive medium which reaches a maximum during the first period of growth for those salts of ammonium derived from strong acids, including phosphoric acid. After the first week of growth the acidity decreases if the anion is absorbed rapidly, as is the case with nitric and phosphoric acids. If the ammonium salt is only slightly soluble, as is the case with ammonium magnesium phosphate, the acid production is avoided.

Rusche (29) concluded from his work with various crops, using 10 gm. of salt per 11.5 kgm. of soil, that ammonium phosphate usually has a good effect, working injuriously only with clover, serradella and rape. All phosphate salts showed some injury to the germination of seeds. With beets the greatest root system was produced by sulfates and the smallest by ammonium nitrate, ammonium phosphate, calcium nitrate, and sodium phosphate. Ammonium phosphates proved injurious to the root systems of alfalfa. The ammonium salts in general were quite injurious. The influence of ammonium phosphate on the parts of the plants above ground was good. Small weights were obtained with chlorides and sulfates with the exception of ammonium sulfate which, like the ammonium phosphate, had a good effect.

EXPERIMENTAL

The experimental work includes the analysis of "Ammo-Phos," biological studies, and various availability experiments in the field and greenhouse, including the effect on lime-requirement and germination. The methods used varied for the different experiments and are discussed as the data are given throughout the thesis.

TABLE 1

Composition of "Ammo-Phos"

	PER CENT
Moisture	4.55
SiO_2	0.50
Al_2O_3	2.30
Fe_2O_3	4.50
K_2O	0.33
Na_2O	1.35
Cl	0.10
CaO	2.52
MgO	0.31
NH_3	13.54
Nitrate	Trace
Total P_2O	43.13
Water-soluble P_2O_5	36.80
Citrate-soluble P_2O_5	4.82
Citrate-insoluble P_2O_5	1.51

TABLE 2

Composition of "Ammo-Phos"

	COMPLETE "AMMO-PHOS"	WATER-SOLUBLE PORTION OF "AMMO-PHOS"	WATER-INSOLUBLE PORTION OF "AMMO-PHOS"	CITRATE-INSOLUBLE PORTION OF "AMMO-PHOS"
Moisture at 100°C	7.14	0.00	1.04	0.84
NH_3	13.58	16.43	6.36	5.51
Water-soluble P_2O_5	35.16	48.98	0.00	0.00
Citrate-soluble P_2O_5	5.76	0.00	37.02	0.00
Citrate-insoluble P_2O_5	1.10	0.00	2.84	44.19
Total P_2O_5	42.02	48.98	39.86	44.19
SO_3	Not det.	Not det.	Trace	0.00
Ca	Not det.	Not det.	1.20	Trace
Fe_2O_3	Not det.	Trace	19.00	Not det.
Al_2O_3	Not det.	Not det.	8.50	Not det.
$Fe_2O_3 + Al_2O_3$	Not det.	Not det.	27.50	23.00
Loss on ignition (red heat)	Not det.	Not det.	18.14	Not det.

ANALYTICAL

A representative sample of the commercial ammonium phosphate ("Ammo-Phos"), made from Tennessee rock phosphate was ground and analyzed for

the more common elements that it seemed probable would be found in the product. The composition in per cent is given in table 1.

An analysis made by the American Cyanamid Company of similar material is given in table 2.

These two analyses bring out the high plant-food content and in addition show that practically all of the phosphorus and nitrogen are present in a readily available form. In addition to containing slightly more than two-thirds as much nitrogen as does sodium nitrate, there is also present in any given quantity nearly three times as much phosphoric acid as is present in a like weight of acid phosphate. As far as the analyses would indicate there are no constituents present that are likely to prove injurious to plant growth.

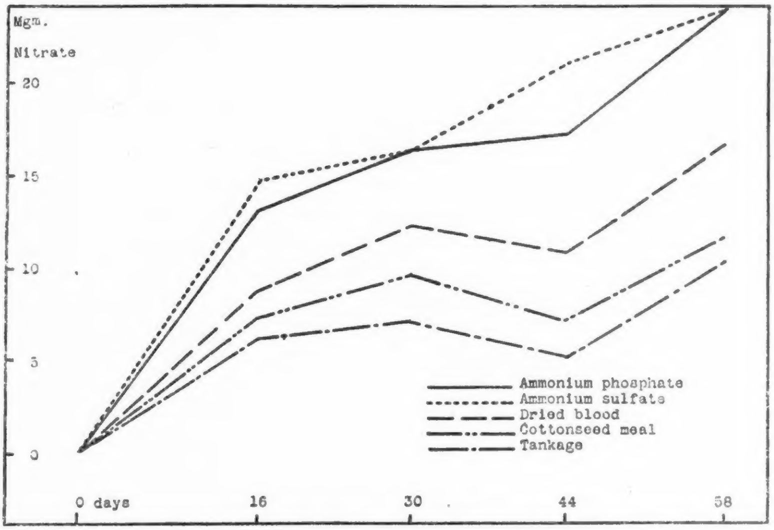

FIG. 1. DIAGRAM SHOWING THE NITRIFICATION OF VARIOUS FERTILIZERS IN FRESH SOIL

BIOLOGICAL

The purpose of the biological studies was primarily to determine the relative availability of ammonium phosphate under different soil conditions as compared with other nitrogenous fertilizers. It is a well known fact that organic fertilizers are rapidly nitrified when placed in the soil under favorable conditions for the action of bacteria and fungi but the formation of nitrates is not as rapid as with ammonium sulfate. Will ammonium phosphate be as rapidly transformed as ammonium sulfate? We should expect this to be the case but possibly the difference in the acid radical would play an important rôle in various soils.

TABLE 3

Nitrification of various fertilizers in fresh soil

TREATMENT	16 DAYS				30 DAYS				44 DAYS				58 DAYS			
	Nitrate nitrogen	Average	Increase over check	Per cent nitrified	Nitrate nitrogen	Average	Increase over check	Per cent nitrified	Nitrate nitrogen	Average	Increase over check	Per cent nitrified	Nitrate nitrogen	Average	Increase over check	Per cent nitrified
	mgm.	*mgm.*	*mgm.*		*mgm.*	*mgm.*	*mgm.*		*mgm.*	*mgm.*	*mgm.*		*mgm.*	*mgm.*	*mgm.*	
Check	1.95				1.25				0.79				2.33			
	1.95	1.95			1.04	1.15			0.74	0.76			2.47	2.40		
Ammonium phosphate	14.28				18.37				17.37				26.77			
	16.17	15.22	13.27	62.60	17.48	17.93	16.78	79.20	18.68	18.02	17.26	81.80	26.41	26.59	24.19	114.81
Ammonium sulfate	18.00				17.99				20.28				25.00			
	15.88	16.94	14.99	71.00	17.73	17.86	16.71	78.80	24.06	22.18	21.42	101.50	24.69	24.84	22.44	106.30
Dried blood	10.90				14.29				11.75				18.89			
	11.25	11.07	9.12	43.00	13.01	13.65	12.50	59.00	12.25	12.00	11.24	53.20	20.16	19.52	17.12	81.20
Cottonseed meal	9.75				11.09				7.89				15.19			
	9.25	9.50	7.55	35.60	11.23	11.16	10.01	47.20	8.98	8.43	7.67	36.40	13.89	14.54	12.14	57.50
Tankage	8.13				8.42				6.58				13.12			
	8.75	8.44	6.49	30.60	8.93	86.80	7.53	35.50	6.31	6.44	5.68	26.90	13.53	13.32	10.92	51.30

Comparative availability of ammonium phosphate with other nitrogenous fertilizers as shown by nitrification

The method adopted was the ordinary tumbler-fresh-soil method, 100-gm. portions of a loam soil being used. In addition to ammonium phosphate, ammonium sulfate, dried blood, cottonseed meal and tankage were used, each tumbler receiving the same amount of nitrogen as that present in 100 mgm. of ammonium sulfate. The soil used was slightly acid and in order to make conditions more favorable for the nitrifying bacteria 0.5 gm. of ground limestone was added to each tumbler. The fertilizers were thoroughly mixed with the soil by means of a soil shaker (16). The tumblers were then allowed to incubate at room temperature for varying lengths of time, as shown in table 3, and the nitrates extracted by leaching from the soil with 500 cc. of water and determined in an aliquot of the filtrate by the phenol-disulfonic acid method. The data are given in table 3 and shown graphically in figure 1.

It will be noticed that ammonium phosphate compares very favorably with ammonium sulfate and the other nitrogenous fertilizers used. The data show that in this particular soil ammonium phosphate does not nitrify quite as rapidly as ammonium sulfate but after one month there is little difference. When compared with dried blood, cottonseed meal and tankage, ammonium phosphate shows a much higher availability. The relative positions of these last-named materials, when compared with the ammonium phosphate fertilizer or with each other, does not change, regardless of the incubation period.

In three cases nitrification of the fertilizer added amounted to more than 100 per cent, doubtless because of the inaccuracy of the phenol-disulfonic acid method in the presence of soluble organic matter, various soluble salts and large amounts of nitrate nitrogen. It is barely possible that the fertilizer stimulated the nitrification of the organic matter of the soil, but this is improbable.

Comparative rate of nitrification of nitrogenous fertilizers in different soils

This experiment was carried out in tumblers with fresh soil according to the method previously given, equivalent amounts of nitrogen (20.7 mgm. per tumbler) being applied in each case. The two soils used were a Penn loam taken from a very fertile garden and a Sassafras loam of medium fertility taken from a meadow. Both soils were slightly acid but 0.5 per cent of calcium carbonate was added to all tumblers to neutralize the acidity. The results obtained are given in table 4 and shown diagrammatically in figures 2 and 3.

It will be noticed that in the garden soil, as in the case of experiments previously reported, ammonium phosphate and ammonium sulfate are both rapidly nitrified and at about the same rate. The differences at the various incubation periods are so slight that they may almost be considered within

TABLE 4

Rate of nitrification of fertilizers in soils

TREATMENT	GARDEN LOAM				MEADOW LOAM			
	Nitrate nitrogen	Average	Increase over check	Per cent nitrified	Nitrate nitrogen	Average	Increase over check	Per cent nitrified
2 weeks								
	mgm.	*mgm.*	*mgm.*		*mgm.*	*mgm.*	*mgm.*	
Acid phosphate	0.72 0.69	0.71			0.52 0.44	0.48		
Ammonium phosphate	9.03 8.89	8.96	8.25	39.85	5.56 6.67	6.11	5.63	27.19
Ammonium sulfate and acid phosphate	6.94 8.35	7.63	6.92	33.43	4.17 4.17	4.17	3.69	17.77
Dried blood and acid phosphate	4.30 4.72	4.51	3.80	18.36	4.03 3.61	3.82	3.34	16.13
Cottonseed meal and acid phosphate	4.72 4.86	4.79	4.08	19.71	2.91 2.99	2.95	2.47	11.93
4 weeks								
Acid phosphate	1.02 0.97	1.00			0.66 0.63	0.65		
Ammonium phosphate	15.29 18.07	16.68	15.68	75.75	11.95 11.12	11.53	10.88	52.56
Ammonium sulfate and acid phosphate	16.68 18.07	17.37	16.37	79.08	13.07 11.12	12.09	11.44	55.26
Dried blood and acid phosphate	10.84 9.73	10.28	9.28	44.83	11.40 9.73	10.56	9.91	47.87
Cottonseed meal and acid phosphate	lost 9.73	9.73	8.73	42.17	6.12 6.67	6.39	5.74	27.72
6 weeks								
Acid phosphate	1.63 1.65	1.64			0.82 0.75	0.79		
Ammonium phosphate	22.80 23.07	22.93	21.29	102.85	12.23 13.90	13.06	12.27	59.27
Ammonium sulfate and acid phosphate	23.07 21.96	22.51	20.87	100.82	14.73 13.90	14.31	13.52	65.31
Dried blood and acid phosphate	16.40 13.90	15.15	13.51	65.26	11.12 lost	11.12	10.33	49.90
Cottonseed meal and acid phosphate	12.79 12.79	12.79	11.15	53.86	7.23 8.06	7.64	6.85	33.09

TABLE 4—(Concluded)

TREATMENT	GARDEN LOAM: Nitrate nitrogen	GARDEN LOAM: Average	GARDEN LOAM: Increase over check	GARDEN LOAM: Per cent nitrified	MEADOW LOAM: Nitrate nitrogen	MEADOW LOAM: Average	MEADOW LOAM: Increase over check	MEADOW LOAM: Per cent nitrified
8 weeks								
	mgm.	*mgm.*	*mgm.*		*mgm.*	*mgm.*	*mgm.*	
Acid phosphate	1.32 1.42	1.37			0.86 0.88	0.87		
Ammonium phosphate	19.11 19.33	19.44	18.07	83.32	13.77 13.77	13.77	12.90	62.31
Ammonium sulfate and acid phosphate	19.11 18.89	19.00	17.63	81.24	14.44 15.11	14.77	13.90	67.15
Dried blood and acid phosphate	11.33 12.00	11.66	10.29	45.57	12.22 11.55	11.88	11.01	53.18
Cottonseed meal and acid phosphate	8.99 8.66	8.82	7.45	34.33	7.33 6.66	6.99	6.12	29.56
10 weeks								
Acid phosphate	1.73 1.73	1.73			0.69 0.78	0.73		
Ammonium phosphate	16.44 17.77	17.10	15.37	74.25	15.11 15.33	15.22	14.49	70.00
Ammonium sulfate and acid phosphate	15.31 14.88	15.19	13.46	65.02	14.22 15.33	14.77	14.04	67.82
Dried blood and acid phosphate	10.22 10.44	10.33	8.60	41.55	10.22 11.11	10.66	9.93	47.97
Cottonseed meal and acid phosphate	8.99 8.99	8.99	7.26	35.07	7.77 7.11	7.44	6.71	32.89

experimental error. Dried blood and cottonseed meal run very nearly together and are much more slowly nitrified than the two ammonium fertilizers. Maximum nitrification was obtained in all cases after 6 weeks' incubation. After this, small amounts of nitrate nitrogen were found because the nitrates had been utilized by bacteria and fungi in the soil for their own growth and consequently were changed over to protein. This protein in turn is nitrified after the microörganisms die.

The results obtained with the meadow soil are in general the same, except that nitrification does not proceed at as rapid a rate as in the garden soil, and the total accumulation of nitrates at any one time is never as large. Ammonium phosphate and ammonium sulfate run close together for the most part, but not quite as consistently so as in the richer soil. Cottonseed meal for

some unknown reason ranks low, while dried blood shows a comparatively high availability as measured by nitrification. Maximum nitrification is obtained in the case of cottonseed meal at the end of 6 weeks, dried blood at the end of 8 weeks and the two ammonium fertilizers at the end of 10 weeks.

The work reported in tables 3 and 4, in so far as it is comparable, agrees in a general way with that of Müntz (26) who in comparative tests of the rate of nitrification of various nitrogenous fertilizers found that at the end of 5 months the relative standings were ammonium sulfate 100, calcium cyanamid 88, dried blood 66 and leather 26.

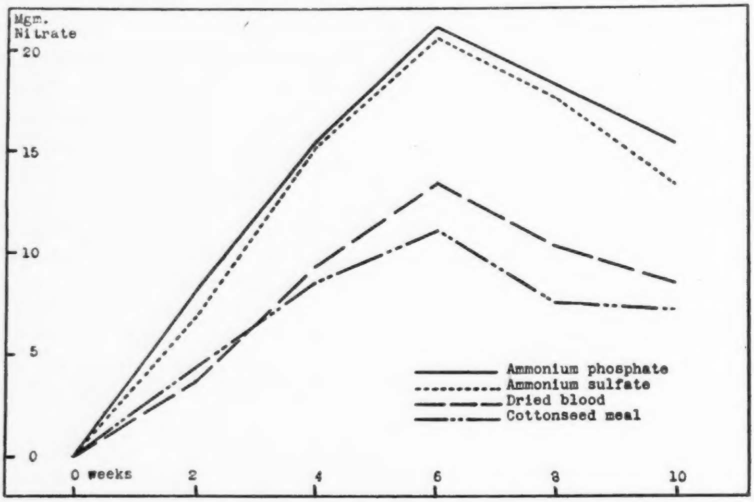

Fig. 2. Diagram Showing the Rate of Nitrification in a Garden Loam Soil

Lipman, Brown and Owen (19) in nitrification experiments, after an incubation period of 4 weeks, obtained the following percentages of recovery of nitrogen as nitrate from various sources of nitrogen:

	per cent
Ammonium sulfate	78.47
Concentrated tankage	53.54
Calcium cyanamid	52.56
Cottonseed meal	30.64
Ground fish	26.15
Dried blood	26.13
Cow manure (solid and liquid, fresh)	12.67
Bone meal	12.31
Cow manure (solid, fresh)	9.46
Horse manure	8.76
Cow manure (solid and liquid, leached)	4.48

The same investigators (20) in another nitrification experiment, after an incubation of 7 weeks, obtained the nitrogen recovery noted below:

	per cent
Ammonium sulfate	73.30
Linseed meal	49.07
Cottonseed meal	42.87
Soybean meal	42.41
Cowpea	33.12
Wheat flour	23.15
Rye flour	13.84

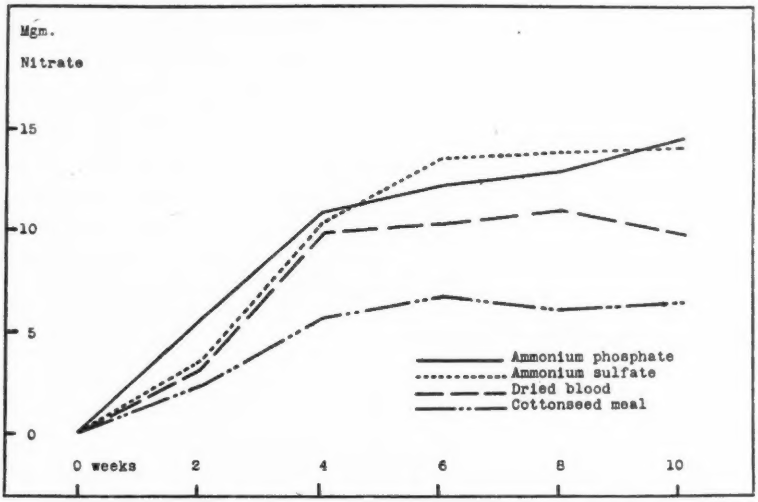

FIG. 3. DIAGRAM SHOWING THE RATE OF NITRIFICATION IN A MEADOW LOAM SOIL

In these experiments the incubation period was for such a long time that no doubt the maximum nitrate production in the case of ammonium sulfate, at least, had been reached prior to the end of the experiment.

The work reported in tables 3 and 4, as well as that of Lipman and that of Müntz, just discussed, brings out very strikingly that as far as the organic forms of nitrogen are concerned the nitrogen-carbon ratio certainly plays an important rôle. The wider the ratio the more difficult it is for the micro-organisms to break down the compounds, and furthermore, the fungi are stimulated to a greater extent. These latter organisms as well as a large portion of the bacteria utilize the nitrates produced for their own growth, and consequently only a comparatively small proportion of the nitrate actually formed from substances of very wide nitrogen-carbon ratio may accumulate. In fact, the added material may actually decrease the amount of nitrates in the soil. On the other hand, ammonium sulfate and ammonium phosphate,

when added to the soil, do not have such a marked effect upon the numbers of organisms, and furthermore, the processes of transformation are less complex. Organic fertilizers must be broken up into peptones, albumoses, amino acids and ammonia, and these in turn nitrified. The process is much longer and requires more energy than the mere converting of ammonia into nitrate.

A discussion of nitrification as a method for the determination of availability would not be complete without referring to the work of Lipman (17) which is in direct contrast with most of the nitrification experiments which have been reported. Using arid soils he found that low-grade nitrogenous materials and ammonium sulfate nitrify much more rapidly than in humid soils, while on the other hand dried blood and other high-grade nitrogenous fertilizers nitrify slowly in these soils. The relative availabilities of the fertilizers were tested out in vegetation experiments and these results confirmed the nitrification data. Considering sodium nitrate as 100, the yields of barley in sand were 82 for calcium nitrate, 139 for ammonium sulfate, 101 for dried blood, 134 for cottonseed meal and 119 for steamed bone meal. Lipman states that "the nitrification method in the direct soil culture, for determining the relative availabilities of nitrogenous fertilizers of the organic or ammonia type, was feasible and more logical and specific in nature than other methods employed heretofore." Under humid conditions other investigators also seem to have obtained reasonably close agreement between nitrification and vegetation tests.

Effect of different forms of lime on the rate of nitrification in soils

The soils selected for this experiment were: first, a very acid sandy loam, so acid in fact that crops did not grow on it except under the most favorable climatic conditions; second, a heavy silt soil only moderately acid and growing good crops each year; and third, a shale loam, fairly fertile and neutral to litmus paper.

The methods used were practically the same as in the nitrification experiments already discussed, 100 gm. of fresh soil per tumbler being used, and the materials thoroughly mixed with the entire sample. Where ammonium sulfate was applied 100 mgm. were added to each tumbler and where ammonium phosphate was used enough was added to supply the same amount of nitrogen as is present in the ammonium sulfate. To all tumblers except the checks and those receiving ammonium phosphate, 586 gm. of acid phosphate were added, thus making the amount of phosphorus the same as in the ammonium phosphate tumblers. Calcium carbonate, where used, was applied at the rate of 1 gm. per tumbler and calcium oxide at the rate of 560 mgm. The incubation period was 26 days. The results are given in table 5 and shown diagrammatically in figure 4.

An examination of this table brings out several points of interest. First, we notice, as has often been shown, that the addition of acid phosphate in-

creases the rate of nitrification of the soil organic matter. The use of calcium oxide, except in the most acid soil, produced a greater stimulation in nitrate production from the soil organic matter than did calcium carbonate. Where ammonium sulfate was applied to the very acid sandy loam soil in the presence of acid phosphate equivalent to that present in ammonium phosphate, the nitrate production was approximately two-thirds of that where ammonium

TABLE 5

Effect of different forms of lime on the rate of nitrification of ammonium phosphate and ammonium sulfate

TREATMENT	SANDY LOAM		SILT		SHALE LOAM	
	Nitrate nitrogen	Average	Nitrate nitrogen	Average	Nitrate nitrogen	Average
	mgm.	mgm.	mgm.	mgm.	mgm.	mgm.
Check	0.79 0.79	0.79	0.79 1.05	0.92	0.79 0.92	0.85
Acid phosphate	1.10 1.05	1.07	1.18 1.05	1.11	0.95 0.95	0.95
Calcium oxide and acid phosphate	3.33 3.19	3.26	3.53 3.24	3.38	4.47 5.00	4.73
Calcium carbonate and acid phosphate	3.53 3.82	3.67	1.32 1.39	1.35	1.66 1.93	1.79
Ammonium sulfate and acid phosphate	1.11 1.11	1.11	7.89 7.94	7.91	10.00 9.65	9.82
Ammonium phosphate	1.94 1.77	1.85	7.91 7.68	7.79	11.67 10.83	11.25
Ammonium sulfate, calcium oxide and acid phosphate	3.28 3.19	3.23	1.85 1.39	1.62	13.39 12.99	13.19
Ammonium phosphate and calcium oxide	2.36 2.36	2.36	2.05 2.89	2.47	10.26 11.17	10.71
Ammonium sulfate, calcium carbonate and acid phosphate	13.23 13.53	13.37	10.88 10.58	10.73	16.65 14.43	15.54
Ammonium phosphate and calcium carbonate	13.81 13.41	13.61	11.84 11.56	11.71	17.11 16.81	16.96

phosphate was used alone, but in both cases the amount of nitrate was only slightly above that in the checks. In the silt loam the difference between the two fertilizers in the absence of lime was within experimental error, but the increases over the checks were very great, showing that the soil was not badly in need of lime. In the shale loam there was a slightly greater accumulation of nitrate from ammonium phosphate than from ammonium sulfate, the difference being approximately 14 per cent in favor of the former fertilizer.

As was previously stated, this soil was neutral to litmus paper and consequently contained a vigorous nitrifying flora which transformed the ammonia rapidly, even without the addition of lime.

In the presence of calcium oxide and acid phosphate, ammonium sulfate showed approximately one-third greater nitrate accumulation in the very

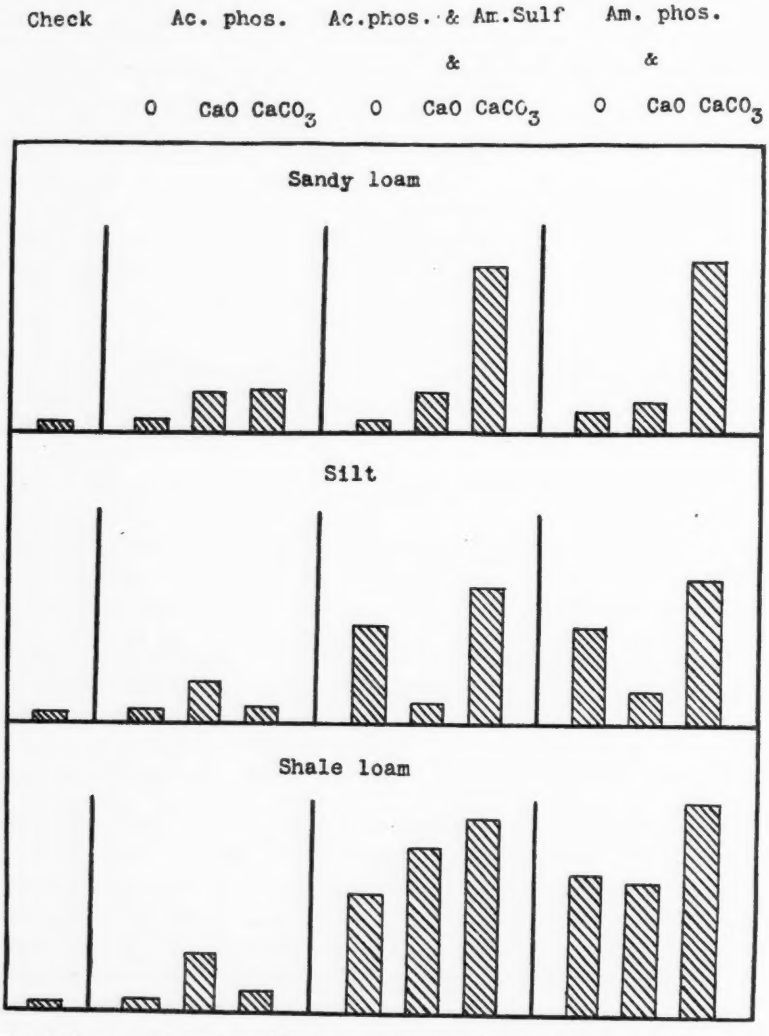

Fig. 4. Diagram Showing the Effect of Different Forms of Lime on the Rate of Nitrification of Ammonium Phosphate and Ammonium Sulfate

acid sandy loam than did ammonium phosphate. In the shale loam there was also a difference of about 23 per cent in favor of ammonium sulfate where calcium oxide was used. However, the reverse is true in the silt loam, ammonium phosphate showing a 50 per cent increase over ammonium sulfate. It is interesting to note that the calcium oxide caused only comparatively slight increases in nitrate production in two soils and an actual depression in the third. Evidently calcium oxide is sufficiently caustic to kill some of the soil organisms, or at least to inhibit their proper multiplication in many cases.

Without exception the soils receiving calcium carbonate showed a greater accumulation of nitrates from both the ammonium fertilizers than any of the other treatments. It happened that in all three soils ammonium phosphate in the presence of calcium carbonate showed a slightly higher availability by nitrification than did ammonium sulfate, but the differences are nearly if not completely within experimental error.

In general, then, from the results reported in table 5 we may say that ammonium phosphate is directly comparable with ammonium sulfate in nitrifiability where acid phosphate is added to the ammonium sulfate in amounts equivalent to the phosphorous in ammonium phosphate. The three soils used were of quite widely different types, yet the fertilizers under a given set of conditions gave similar results.

Effect of ammonium phosphate upon ammonification

In order to determine if the addition of a fertilizer, like ammonium phosphate, which contains all of its nitrogen in the form of ammonia, would hinder the ammonification of organic matter added to the soil, the experiment recorded in table 6 was carried out. The soil chosen was a neutral sandy loam from the college farm, 100-gm. samples being weighed out into tumblers and the dried blood, green alfalfa and cottonseed meal thoroughly mixed with the sample according to the method followed in the nitrification experiments. Dried blood was applied at the rate of 2 gm. per tumbler, which expressed as nitrogen amounts to 252 mgm. The cottonseed meal and green alfalfa were analyzed and sufficient added to equal the nitrogen in the dried blood. After incubation at room temperature for 8 days the ammonia which had accumulated was determined by distillation with magnesium oxide. These results are given in table 6 and figure 5.

A study of the ammonification results shows that, in general, as the quantity of ammonium phosphate increases the amount of ammonia produced from dried blood decreases. The reverse is true of cottonseed meal, while the rate of ammonification of alfalfa remains practically constant. The large amount of ammonia produced from green alfalfa is especially significant, showing how rapidly the material will decay under favorable conditions. The depression of ammonification of dried blood where ammonium phosphate is used as contrasted with the increase with cottonseed meal is to be expected,

TABLE 6

Effect of ammonium phosphate upon ammonification

TREATMENT	NH_3 NITROGEN	AVERAGE	INCREASE OVER CHECK	PER CENT AMMONIFIED
	mgm.	*mgm.*	*mgm.*	
Check	1.69 1.47	1.58		
Dried blood	85.80 86.24	86.02	85.44	33.90
Cottonseed meal	66.79 67.75	67.27	65.69	26.07
Alfalfa	64.97 58.86	61.91	60.33	23.94
20 mgm. ammonium phosphate	1.47 1.84	1.65		
20 mgm. ammonium phosphate and dried blood	83.88 82.83	83.35	81.70	32.42
20 mgm. ammonium phosphate and cottonseed meal	71.89 73.97	72.93	71.28	28.28
20 mgm. ammonium phosphate and alfalfa	64.20 60.38	62.29	60.64	24.06
40 mgm. ammonium phosphate	2.84 3.03	2.93		
40 mgm. ammonium phosphate and dried blood	77.71 79.90	78.80	75.87	30.11
40 mgm. ammonium phosphate and cottonseed meal	71.69 73.10	72.39	69.46	27.56
40 mgm. ammonium phosphate and alfalfa	65.85 58.04	61.94	59.01	23.41
80 mgm. ammonium phosphate	7.61 6.42	7.01		
80 mgm. ammonium phosphate and dried blood	89.15 87.46	88.30	81.29	32.26
80 mgm. ammonium phosphate and cottonseed meal	80.79 85.27	83.03	76.02	30.16
80 mgm. ammonium phosphate and alfalfa	69.13 66.37	67.75	60.74	24.10
120 mgm. ammonium phosphate	11.64 11.74	11.69		
120 mgm. ammonium phosphate and dried blood	lost 91.19	91.19	79.50	31.15
120 mgm. ammonium phosphate and cottonseed meal	84.57 86.22	85.39	73.70	29.24

TABLE 6 (Concluded)

TREATMENT	NH₃ NITROGEN	AVERAGE	INCREASE OVER CHECK	PER CENT AMMONIFIED
	mgm.	*mgm.*	*mgm.*	
120 mgm. ammonium phosphate and alfalfa	69.48 73.31	71.39	59.70	23.69
160 mgm. ammonium phosphate	16.60 16.80	16.70		
160 mgm. ammonium phosphate and dried blood	87.56 95.62	91.59	74.89	29.71
160 mgm. ammonium phosphate and cottonseed meal	95.37 100.30	97.83	81.13	32.19
160 mgm. ammonium phosphate and alfalfa	76.69 78.06	77.37	60.67	24.06
200 mgm. ammonium phosphate	20.78 21.47	21.12		
200 mgm. ammonium phosphate and dried blood	99.19 93.07	96.13	75.01	29.76
200 mgm. ammonium phosphate and cottonseed meal	97.16 93.89	95.52	74.40	29.52
200 mgm. ammonium phosphate and alfalfa	82.05 78.80	80.42	59.30	23.53
300 mgm. ammonium phosphate	32.67 32.03	32.35		
300 mgm. ammonium phosphate and dried blood	105.35 103.66	104.50	72.15	28.63
300 mgm. ammonium phosphate and cottonseed meal	115.15 122.02	128.58	96.23	38.18
300 mgm. ammonium phosphate and alfalfa	100.74 93.53	97.13	64.78	25.71
1000 mgm. ammonium phosphate	105.25 105.05	105.15		
1000 mgm. ammonium phosphate and dried blood	163.38 173.13	168.25	63.10	25.04
1000 mgm. ammonium phosphate and cottonseed meal	204.27 192.04	198.15	93.00	36.91
1000 mgm. ammonium phosphate and alfalfa	169.95 159.42	164.67	59.52	23.62

since ammonium salts, and especially ammonium phosphate, stimulate the growth of fungi, which in turn can decompose cottonseed meal more rapidly than dried blood because of its wider nitrogen-carbon ratio.

Other investigators have reported similar results, among them being Lipman and Brown (18), who observed that sodium nitrate favors the growth of decay

bacteria. They attributed this to the fact that many saprophytic bacteria use nitrate and its presence, by increasing their numbers and vigor, results in an increased destruction of the humus. On the other hand, ammonium salts had a depressing effect upon the growth of bacteria but favored the fungi. The work here reported with ammonium phosphate, in general, gave similar results and agrees with the conclusions of these investigators concerning ammonium sulfate.

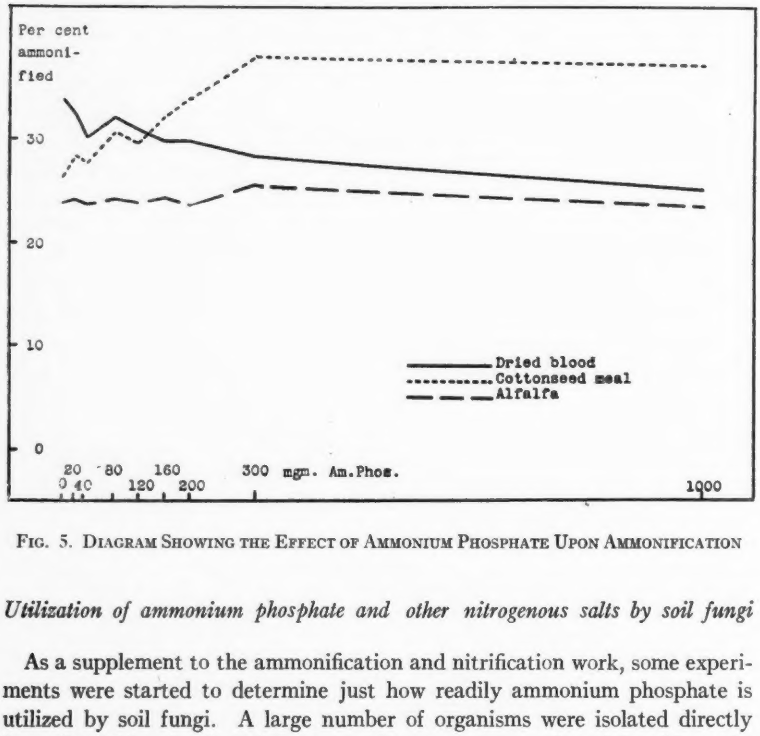

FIG. 5. DIAGRAM SHOWING THE EFFECT OF AMMONIUM PHOSPHATE UPON AMMONIFICATION

Utilization of ammonium phosphate and other nitrogenous salts by soil fungi

As a supplement to the ammonification and nitrification work, some experiments were started to determine just how readily ammonium phosphate is utilized by soil fungi. A large number of organisms were isolated directly from the field and a few of the most vigorous growers selected for this work. In the first series pure tri-basic ammonium phosphate was used for comparison with ammonium sulfate. Almost without exception the growth obtained with the six organisms used was greater in the flasks containing the ammonium phosphate. A later series comparing ammonium phosphate with ammonium sulfate, ammonium nitrate, urea, ammonium carbonate, sodium nitrate, and a mixture of ammonium sulfate and sodium nitrite, five pure cultures of soil fungi, being used, again showed ammonium phosphate to be more favorable to the organisms than ammonium sulfate. However, the ammonium carbonate medium was nearly as good as the ammonium phosphate. At the end

of the thirteenth day the ranking, as far as growth was concerned, was as follows:

First	Ammonium phosphate
Second	Ammonium carbonate
Third	Ammonium sulfate
Fourth	Urea
Fifth	Ammonium nitrate
Sixth	Sodium nitrate
Seventh	Ammonium sulfate and sodium nitrite (no growth in most cases)

One of the organisms used gave very poor growth in all cases except where the nitrogen supplied was in the form of ammonium phosphate.

The fact that soil bacteria and fungi can utilize ammonium phosphate as well as and often better than any other ammonium salt may or may not be a point in favor of the phosphate. Since the phosphate favors the growth of the organisms of the soil it necessarily means that more of the nitrogen will be converted into insoluble protein when it becomes a part of the organism itself; thus the ammonia or nitrate produced from it is taken away from the use of the plant. The nitrogen fixed in this manner will again be made available later when the organisms die and undergo decomposition. The rate at which these processes may occur in the soil is not well enough known to justify a definite statement as to the probability of the growth of the micro-organisms interfering with proper plant nourishment and development. Under normal conditions it is reasonable to suppose that the increased growth of bacteria and fungi following the application of ammonium phosphate would also act favorably on plant growth. Increased bacterial action causes more insoluble plant-food in the soil to become available and also hastens the decay of organic matter. The storing up of the nitrogen in the bodies of the soil organisms would merely fix it for the present and prevent a big stimulation of plant growth at the very first, followed by a decrease later, as often occurs when sodium nitrate is applied. There is still another factor to be considered. Under field conditions fertilizers are most commonly applied at about the time of planting. It is a month or longer, depending upon the crop being grown, before the plants will require very much nitrogen. The stimulation of bacteria and fungi, then, will result in the fixation of the nitrogen applied more quickly. In general, any change in the condition of the soil that has a beneficial effect on the bacteria in the soil will act favorably on the plants also.

Pot experiments

The purpose of these experiments was to determine the relative availability of the nitrogen and of the phosphorous in the ammonium phosphate fertilizer under varying soil conditions and with different soils. The effect of the common fertilizers on soil reaction also was among the points considered, especially in relation to the availability of each of the fertilizers. The ques-

tions, does ammonium phosphate show a residual effect and how is the soil affected by long continued use, also are at least partially answered.

Comparative availability of various nitrogenous fertilizers and their effect upon soil reaction under greenhouse conditions

For this experiment two soils were selected, a Norfolk sand and a Sassafras loam. The first of these was light in texture, low in fertility and had a lime-requirement of 714 pounds of calcium carbonate per 3,000,000 pounds of soil. The second was low in crop production, also, probably because of acidity rather than lack of nitrogen, phosphorous or potassium. Its lime-requirement was found to be 5000 pounds of calcium carbonate per acre. The soils were air-dried, sieved and weighed out into pots holding 20 pounds of soil. The fertilizers applied in addition to ammonium phosphate were ammonium sulfate, dried blood, and cottonseed meal. Two rates of application were made, namely, 1.5 gm. and 3 gm. of ammonium phosphate per pot and equivalent amounts of nitrogen in the case of the other three fertilizers. Half of the pots received lime and the other half were left unlimed. In all cases where lime was applied enough was used to neutralize the acidity and 2 tons of calcium carbonate in excess. Two grams of potassium chloride were added to all pots and enough 16 per cent acid phosphate was applied to those pots not receiving ammonium phosphate to equal the phosphorous in this fertilizer. This was more phosphorous than the plants actually required but it was necessary to use this amount in order to eliminate the element as a variable factor. As is brought out later in the germination experiments, very large quantities of acid phosphate are required to injure plants and therefore the excess would not be expected to cause an injury. The fertilizers were mixed with the entire 20 pounds of soil, and barley planted on December 31, 1915. Soon after the plants were up mildew attacked them so badly that the crop was harvested on February 10 when the plants were about 10 inches in height. The plants were dried and analyzed and the results reported in table 7.

No importance should be attached to these results since in many cases the fungus greatly decreased the yields. Immediately after harvesting the barley the pots were planted to buckwheat. This crop was chosen because of its quick growth and adaptability to greenhouse conditions and, above all, because it is not attacked by the downy mildew. The yields and analyses are given in table 8.

After removing the crop the pots were again planted to buckwheat without the use of additional fertilizer. The results are given in table 9. As will be noticed from the yields of the last crop the available plant-food had been practically exhausted by the barley and the two residual crops of buckwheat. The total yields of dry matter and the recoveries of nitrogen from these three crops are summarized in table 10.

A glance at the summary table gives a fair indication of the availability

TABLE 7

Comparative availability of various nitrogenous fertilizers in soil under greenhouse conditions
First crop (barley)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK
	Norfolk sand (167 mgm. of nitrogen added)								
	Unlimed								
		grams	*grams*	*gram*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*
1	Check..............	1.878			2.77		52.0		
2		1.707	1.793		3.17	2.97	54.1	53.05	
3	Ammonium phos-	2.406			4.22		101.5		
4	phate.............	2.278	2.342	0.549	3.90	4.06	88.9	95.20	42.15
5	Ammonium sulfate...	2.342			4.01		94.0		
6		2.356	2.349	0.556	4.01	4.01	94.4	94.20	41.15
7	Dried blood.........	2.192			3.55		77.7		
8		2.418	2.305	0.512	3.52	3.54	85.2	81.45	28.40
9	Cottonseed meal.....	2.269			3.53		80.0		
10		2.255	2.262	0.469	3.60	3.57	81.1	80.55	27.50
	Limed								
11	Check..............	2.023			3.24		65.6		
12		1.713	1.868		3.53	3.39	60.4	63.00	
13	Ammonium phos-	2.013			3.78		76.0		
14	phate............	2.127	2.070	0.202	3.78	3.78	80.3	78.15	15.15
15	Ammonium sulfate...	1.768			3.89		68.7		
16		2.007	1.888	0.020	3.67	3.78	73.7	71.20	8.20
17	Dried blood.........	2.143			3.50		75.0		
18		1.810	1.977	0.109	3.77	3.64	68.2	71.60	8.60
19	Cottonseed meal.....	2.079			3.81		79.2		
20		1.965	2.022	0.154	3.64	3.73	71.6	75.40	12.40
	Sassafras loam (167 mgm. of nitrogen added)								
	Unlimed								
21	Check..............	2.304			4.42		101.80		
22		2.805	2.555		4.18	4.30	117.26	109.53	
23	Ammonium phos-	2.377			4.33		102.98		
24	phate.............	1.958	2.168	0.387	4.47	4.40	87.60	95.29	−14.24
25	Ammonium sulfate...	2.458			4.48		108.34		
26		2.176	2.317	−0.238	4.63	4.56	100.70	104.52	− 5.01
27	Dried blood.........	2.130			4.35		92.70		
28		2.636	2.383	−0.172	4.35	4.35	114.60	103.65	− 5.88
29	Cottonseed meal.....	2.301			4.41		101.40		
30		2.091	2.196	−0.359	4.51	4.46	94.30	97.85	−11.68

TABLE 7—(Continued)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK
Limed									
		grams	grams	gram	per cent	per cent	mgm.	mgm.	mgm.
31	Check	2.283			4.52		103.15		
32		2.721	2.452		4.79	4.66	130.45	116.80	
33	Ammonium phosphate	2.096			5.10		106.80		
34		2.471	2.283	−0.169	4.47	4.79	110.55	108.67	− 8.13
35	Ammonium sulfate	1.954			5.28		103.20		
36		2.264	2.109	−0.343	4.61	4.95	105.75	104.47	−12.33
37	Dried blood	2.206			4.96		109.48		
38		2.368	2.287	−0.165	4.61	4.79	108.90	109.19	− 7.61
39	Cottonseed meal	2.071			4.51		93.45		
40		2.341	2.206	−0.246	4.25	4.38	99.55	96.47	−20.33
Norfolk sand (334 mgm. of nitrogen added)									
Unlimed									
41	Check	1.927			3.12		60.20		
42		2.028	1.978		3.08	3.10	62.40	61.30	
43	Ammonium phosphate	2.941			3.98		117.05		
44		2.363	2.656	0.678	4.03	4.01	95.25	106.15	44.85
45	Ammonium sulfate	2.354			4.10		96.60		
46		2.919	2.637	0.659	4.28	4.19	125.00	110.80	49.50
47	Dried blood	2.709			3.87		104.80		
48		2.265	2.487	0.509	3.87	3.87	87.70	96.25	34.95
49	Cottonseed meal	2.656			3.98		105.80		
50		2.697	2.677	0.699	3.94	3.96	106.15	105.97	44.67
Limed									
51	Checked	1.883			4.28		80.70		
52		2.102	1.993		3.27	3.78	68.80	74.75	
53	Ammonium phosphate	2.321			3.82		88.10		
54		2.565	2.443	0.451	3.57	3.70	87.20	87.65	12.90
55	Ammonium sulfate	2.079			4.03		83.80		
56		2.532	2.306	0.313	3.93	3.98	99.45	91.62	16.87
57	Dried blood	2.318			3.94		91.25		
58		2.266	2.292	0.299	3.76	3.85	85.30	88.27	13.52
59	Cottonseed meal	2.552			3.73		95.10		
60		2.626	2.589	0.597	3.75	3.74	98.25	96.67	21.92
Sassafras loam (334 mgm. of nitrogen added)									
Unlimed									
61	Check	3.333			4.37		145.70		
62		3.745	3.539		4.35	4.36	162.80	154.25	
63	Ammonium phosphate	3.224			4.42		142.65		
64		3.123	3.177	−0.362	4.48	4.45	140.10	141.37	−12.88

TABLE 7—(Concluded)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK
	Sassafras loam (334 mgm. of nitrogen added)								
Unlimed									
		grams	grams	gram	per cent	per cent	mgm.	mgm.	mgm.
65	Ammonium sulfate...	3.640			4.46		162.30		
66		3.436	3.538	−0.001	4.26	4.36	146.36	154.33	0.08
67	Dried blood.........	3.983			4.35		173.30		
68		4.224	4.104	0.565	4.79	4.57	202.20	187.75	33.50
69	Cottonseed meal.:...	4.216			4.30		181.24		
70		4.579	4.398	0.859	4.17	4.24	191.24	186.24	31.99
Limed									
71	Check..............	4.406			4.34		191.42		
72		4.173	4.290		4.64	4.49	194.25	192.83	
73	Ammonium phos-	3.485			4.61		160.68		
74	phate.............	3.649	3.567	−0.723	4.56	4.59	166.35	163.51	−29.32
75	Ammonium sulfate...	3.732			4.55		169.76		
76		3.431	3.583	−0.707	4.62	4.59	158.65	164.20	−28.63
77	Dried blood.........	3.809			4.48		170.70		
78		3.748	3.779	−0.511	4.50	4.49	168.66	169.68	−23.15
79	Cottonseed meal.....	3.169			4.41		139.60		
80		3.656	3.413	−0.877	4.59	4.50	168.10	153.85	−38.98

of ammonium phosphate as compared with other nitrogenous fertilizers. While in most cases the comparative availability of any two fertilizers is very nearly the same whether judged from the standpoint of crop yield or the recovery of nitrogen, it is better in this particular case to use the recovery of nitrogen as a basis of comparison, since two different kinds of crops were grown.

In the case of pots 1 to 10, containing Norfolk sand without lime, ammonium phosphate ranked appreciably above ammonium sulfate and very much above the two organic fertilizers. When the same soil was limed the ratio of one fertilizer to another was practically the same, except that for some unknown reason cottonseed meal gave very much lower results.

Referring to pots 41 to 60, where the same experiment was repeated except that twice as much nitrogen was applied, it will be noticed that the same ratios hold true. However, ammonium sulfate gave yields more nearly equal to ammonium phosphate, especially in the unlimed soil. The highest percentage recovery of the nitrogen applied was 69.94 per cent.

As previously stated the Norfolk sand was very poor and only slightly acid, thus explaining why liming failed to cause any decided increases in crop yields. Considering the recovery of nitrogen in the Sassafras loam it will be noticed in the summary table that for pots 21 to 30, which were unlimed,

TABLE 8

Comparative availability of various nitrogenous fertilizers in soil under greenhouse conditions
Second crop (Buckwheat)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK
	Norfolk sand								
	Unlimed								
		grams	*grams*	*grams*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*
1	Check	4.6			1.29		59.34		
2		4.0	4.3		1.16	1.23	46.40	52.87	
3	Ammonium phosphate	15.4			0.73		112.42		
4		16.7	16.05	11.75	0.72	0.73	120.24	116.33	63.46
5	Ammonium sulfate	15.7			0.68		106.76		
6		14.4	15.05	10.75	0.73	0.71	105.12	105.94	63.97
7	Dried blood	11.2			0.83		92.96		
8		10.6	10.9	6.60	1.12	0.98	118.72	105.84	52.97
9	Cottonseed meal	10.5			0.83		87.15		
10		11.0	10.75	6.45	0.83	0.83	91.30	89.23	36.36
	Limed								
11	Check	10.9			1.03		112.27		
12		10.6	10.75		0.92	0.98	97.52	104.90	
13	Ammonium phosphate	26.2			0.70		183.40		
14		22.5	24.35	13.60	0.80	0.75	180.00	181.70	76.80
15	Ammonium sulfate	20.0			0.86		162.00		
16		22.8	21.40	10.65	0.74	0.80	168.72	165.36	60.46
17	Dried blood	20.2			0.79		159.58		
18		20.6	20.40	9.65	0.81	0.80	166.86	163.22	58.32
19	Cottonseed meal	17.0			0.82		139.40		
20		15.7	16.35	5.60	0.86	0.84	135.02	137.21	32.31
	Sassafras loam								
	Unlimed								
21	Check	24.8			0.99		245.52		
22		25.0	24.90		0.99	0.99	247.52	246.51	
23	Ammonium phosphate	26.3			1.15		302.45		
24		35.0	30.65	5.75	0.97	1.06	304.50	303.23	56.72
25	Ammonium sulfate	25.3			1.29		326.37		
26		27.0	26.15	1.25	1.36	1.32	367.20	346.79	100.75
27	Dried blood	29.0			1.11		321.90		
28		33.2	31.10	6.20	1.06	1.09	351.92	336.91	90.40
29	Cottonseed meal	30.2			1.12		338.24		
30		29.4	29.80	4.90	1.05	1.09	308.70	323.47	76.96

TABLE 8—(Continued)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK
Limed									
		grams	*grams*	*grams*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*
31	Check	37.6			0.85		319.60		
32		32.3	34.95		0.87	0.86	281.01	300.31	
33	Ammonium phos-	lost							
34	phate	36.6	36.6	1.65	1.18	1.180	431.88	431.88	131.57
35	Ammonium sulfate	lost							
36		36.8	36.80	1.85	1.12	1.120	412.16	412.16	111.85
37	Dried blood	lost							
38		37.8	37.80	2.85	1.03	1.030	389.34	389.34	89.03
39	Cottonseed meal	30.0			1.01		303.00		
40		37.2	33.60	−1.35	0.96	0.985	357.12	330.06	29.75
Norfolk sand									
Unlimed									
41	Check	6.8			1.01		68.68		
42		5.1	5.95		1.21	1.110	61.71	65.20	
43	Ammonium phos-	35.5			0.63		223.65		
44	phate	35.5	35.50	29.55	0.67	0.650	237.85	230.75	165.55
45	Ammonium sulfate	32.5			0.71		230.75		
46		34.8	33.65	27.70	0.62	0.665	215.76	223.26	158.56
47	Dried blood	24.3			0.70		170.10		
48		26.8	25.55	19.60	0.73	0.715	195.64	182.87	117.67
49	Cottonseed meal	21.5			0.73		156.95		
50		21.0	21.25	15.30	0.74	0.735	155.40	156.18	90.98
Limed									
51	Check	9.1			0.90		81.90		
52		10.3	9.70		0.87	0.89	89.61	85.76	
53	Ammonium phos-	34.6			0.83		287.18		
54	phate	33.8	34.20	24.50	0.83	0.83	280.54	283.86	198.10
55	Ammonium sulfate	33.4			0.82		273.88		
56		34.7	34.05	24.35	0.79	0.81	274.13	274.01	188.25
57	Dried blood	23.2			0.85		197.20		
58		31.6	27.40	17.70	0.83	0.84	265.44	231.32	145.56
59	Cottonseed meal	24.8			0.83		205.84		
60		20.0	22.40	12.70	0.87	0.85	174.00	189.92	104.16

TABLE 8—(Concluded)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK
				Sassafras loam					
Unlimed									
		grams	*grams*	*grams*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*
61	Check	21.5			1.02		219.30		
62		17.6	19.55		1.33	1.18	234.08	226.69	
63	Ammonium phosphate	36.5			1.18		430.70		
64		36.6	36.55	17.00	1.19	1.19	435.54	433.12	206.43
65	Ammonium sulfate	21.5			2.09		449.50		
66		23.0	22.25	3.70	2.19	2.14	503.70	476.60	249.91
67	Dried blood	28.2							
68		lost	28.20	8.65	1.41	1.41	397.62	397.62	170.93
69	Cottonseed meal	25.8			1.18		304.44		
70		28.6	27.20	7.65	1.17	1.18	334.62	319.53	92.84
Limed									
71	Check	28.6			1.04		297.44		
72		38.4	33.50		1.08	1.06	414.72	356.08	
73	Ammonium phosphate	43.8			1.07		468.66		
74		40.5	42.15	8.65	1.07	1.07	433.35	451.01	94.93
75	Ammonium sulfate	44.5			1.10		489.50		
76		45.5	45.00	11.50	1.03	1.07	468.65	479.08	123.00
77	Dried blood	35.6			1.08		384.48		
78		40.8	38.20	4.70	1.02	1.05	416.16	400.32	44.24
79	Cottonseed meal	36.4			1.05		382.20		
80		38.7	37.55	4.05	1.02	1.04	394.74	388.47	32.39

ammonium sulfate ranked first, ammonium phosphate second, and dried blood and cottonseed meal, third and fourth, respectively. When lime, was used, the recovery from ammonium phosphate was nearly 7 per cent higher than from ammonium sulfate and decidedly above that from the two organic fertilizers.

In pots 61 to 80 where large quantities of nitrogen were used similar results were obtained, with the exception that ammonium phosphate stood second in both cases. This Sassafras loam which was not very much heavier than the Norfolk sand was more acid and richer in nitrogen. This explains the results obtained, especially as regards the low recovery of nitrogen in most cases. Liming made the nitrogen already in the soil available, so that fertilizers did not always show large increases. It is to be regretted that "damping-off" fungi attacked the young plants in a few of the pots and results from these cannot be given. Pots 33, 35 and 37 accidently received an application of fertilizer after the crop of barley was grown and these must be eliminated in considering the data.

TABLE 9

Comparative availability of various nitrogenous fertilizers in soil under greenhouse conditions
Third crop (buckwheat)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK
	Norfolk sand								
Unlimed									
		grams	*grams*	*grams*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*
1	Check	0.0			0.00		0.00		
2		0.1	0.05		2.10	2.10	2.10	1.05	
3	Ammonium phosphate	0.1			2.10		2.10		
4		0.6	0.35	0.30	1.85	1.98	10.90	6.50	5.45
5	Ammonium sulfate	0.1			2.05		2.05		
6		0.0	0.05	0.00	0.00	2.05	0.00	1.02	−0.03
7	Dried blood	0.6			1.75		10.50		
8		0.1	0.35	0.30	2.00	1.88	2.00	6.25	5.20
9	Cottonseed meal	0.6			1.99		11.90		
10		0.3	0.45	0.40	1.77	1.88	5.30	8.55	7.50
Limed									
		grams	*grams*	*grams*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*
11	Check	0.6			1.85		11.10		
12		1.0	0.80		1.71	1.78	17.10	14.10	
13	Ammonium phosphate	1.9			1.66		31.54		
14		1.4	1.65	0.85	1.75	1.71	24.50	28.02	13.92
15	Ammonium sulfate	2.7			1.54		41.58		
16		1.2	1.95	1.15	1.51	1.53	18.12	29.85	15.75
17	Dried blood	2.0			1.59		31.80		
18		1.8	1.90	1.10	1.34	1.47	24.12	27.96	13.86
19	Cottonseed meal	0.4			1.85		7.40		
20		1.3	0.85	0.05	1.14	1.50	14.82	11.11	−2.99
	Sassafras loam								
Unlimed									
21	Check	2.4			1.41		33.84		
22		2.0	2.20		1.74	1.58	34.80	34.32	
23	Ammonium phosphate	2.9			1.88		54.52		
24		1.9	2.40	−0.20	1.69	1.79	32.11	43.32	9.00
25	Ammonium sulfate	1.2			2.00		24.00		
26		2.5	1.85	−0.35	1.55	1.78	38.75	31.38	−2.94
27	Dried blood	1.0			2.36		23.60		
28		2.1	1.55	−0.65	1.67	2.12	35.07	29.34	−4.98
29	Cottonseed meal	2.0			1.73		34.60		
30		1.9	1.95	−0.25	1.91	1.82	36.29	35.45	1.13

TABLE 9—(Continued)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK
	Sassafras loam								
Limed									
31	Check..............	2.5			1.89		47.25		
32		4.4	3.45		1.59	1.74	69.96	58.61	
33	Ammonium phos-	lost							
34	phate............	3.1	3.10	−0.35	1.73	1.73	53.63	53.63	−4.98
35	Ammonium sulfate...	lost							
36		4.0	4.00	0.55	1.67	1.67	66.80	66.80	8.19
37	Dried blood..........	lost							
38		4.3	4.30	0.85	1.53	1.53	65.79	65.79	7.18
39	Cottonseed meal.....	5.3			1.73		91.69		
40		3.0	4.15	0.70	1.87	1.80	56.10	73.90	15.29
	Norfolk sand								
Unlimed									
		grams	*grams*	*grams*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*
41	Check..............	0.0			0.00		0.00		
42		0.0	0.00		0.00	0.00	0.00	0.00	
43	Ammonium phos-	0.3			2.58		7.74		
44	phate............	0.2	0.25	0.25	2.62	2.60	5.24	6.49	6.49
45	Ammonium sulfate...	0.2			2.62		5.24		
46		0.1	0.15	0.15	2.50	2.56	2.50	3.87	3.87
47	Dried blood..........	0.4			2.33		9.32		
48		0.6	0.50	0.50	1.68	2.01	10.08	9.70	9.70
49	Cottonseed meal.....	0.1			2.05		2.05		
50		0.9	0.50	0.50	2.11	2.08	18.99	10.52	10.52
Limed									
51	Check..............	0.5			2.41		11.05		
52		0.0	0.25		0.00	2.41	0.00	5.53	
53	Ammonium phos-	1.2			2.21		26.52		
54	phate............	1.7	1.45	1.20	1.75	1.98	29.75	28.14	22.61
55	Ammonium sulfate...	0.8			2.01		16.08		
56		0.2	0.50	0.25	1.91	1.96	3.82	9.95	4.42
57	Dried blood..........	1.6			1.98		31.68		
58		1.9	1.75	1.50	2.73	2.36	51.87	41.78	36.25
59	Cottonseed meal.....	0.0		0.00	0.00		0.00		
60		0.7	0.35	0.10	2.01	2.01	14.07	7.04	1.51

TABLE 9—(Concluded)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK
				Sassafras loam					
Unlimed									
		grams	*grams*	*grams*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*
61	Check	0.5			2.39		11.95		
62		2.0	1.25		1.77	2.08	35.40	23.68	
63	Ammonium phosphate	2.0			1.90		38.00		
64		2.0	2.00	0.75	2.31	2.11	46.20	42.10	18.42
65	Ammonium sulfate	2.5			2.36		59.00		
66		2.3	2.40	1.15	2.17	2.27	49.91	54.46	30.78
67	Dried blood	2.5			2.05		51.25		
68		lost	2.50	1.25		2.05		51.25	27.57
69	Cottonseed meal	2.6			1.89		49.14		
70		1.5	2.05	0.80	2.73	2.31	40.95	45.07	21.39
Limed									
71	Check	2.7			2.13		57.51		
72		5.5	4.10		1.81	1.97	99.55	78.53	
73	Ammonium phosphate	3.2			1.79		57.28		
74		5.0	4.10	0.00	1.75	1.77	87.50	72.39	−6.14
75	Ammonium sulfate	2.6			1.84		47.84		
76		3.6	3.10	−1.00	1.57	1.71	56.52	52.18	−26.15
77	Dried blood	4.2			1.70		61.40		
78		3.6	3.90	−0.20	1.85	1.78	66.60	64.00	−14.53
79	Cottonseed meal	5.3			1.76		93.28		
80		4.5	4.90	0.80	1.80	1.78	81.00	87.14	8.61

One peculiarity is brought out in the results, namely, the low crop yield in the unlimed ammonium sulfate pots as compared with ammonium phosphate, but the very much higher percentage of nitrogen in the crop. It is barely possible that under the existing acid conditions the nitrogen of ammonium sulfate is less efficient as far as increasing crop growth is concerned, but the writer does not wish to state this definitely.

From the results as a whole one might say on first thought that ammonium phosphate would give better results if applied on light sandy soils while the reverse would be true for ammonium sulfate, but the data given do not prove this point. Undoubtedly the chemical and biological differences between the two soils are much greater factors than the mere textural differences. Other sandy or loam soils would probably give entirely different results.

As has been previously shown by various investigators dried blood and cottonseed meal rank much lower in availability than ammonium sulfate. In both soils used in this experiment dried blood showed a tendency to produce larger yields than cottonseed meal. The residual effect which is often claimed

TABLE 10

Comparative availability of various nitrogenous fertilizers in soil under greenhouse conditions
Summary—First three crops

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	TOTAL NITROGEN RECOVERED	AVERAGE	INCREASE OVER CHECK	PER CENT RECOVERED
	Norfolk sand (167 mgm. of nitrogen added)							
Unlimed								
		grams	*grams*	*grams*	*mgm.*	*mgm.*	*mgm.*	
1	Check	6.49			111.34			
2		5.81	6.15		102.60	106.97		
3	Ammonium phosphate	17.91			216.02			
4		19.58	18.75	12.60	220.04	218.03	111.06	66.50
5	Ammonium sulfate	18.14			202.86			
6		16.76	17.45	11.30	199.52	201.19	94.22	56.41
7	Dried blood	13.99			181.16			
8		13.12	13.56	7.41	202.17	191.67	84.70	50.72
9	Cottonseed meal	13.37			179.05			
10		13.56	13.47	7.32	177.70	178.38	71.41	42.76
Limed								
11	Check	13.52			188.97			
12		13.31	13.42		172.02	180.50		
13	Ammonium phosphate	30.11			290.94			
14		26.03	28.07	14.65	284.80	287.87	107.37	64.29
15	Ammonium sulfate	24.47			272.28			
16		26.01	25.24	11.82	260.54	266.41	85.91	51.44
17	Dried blood	24.34			266.38			
18		24.21	24.28	10.86	259.18	262.78	82.28	49.27
19	Cottonseed meal	19.48			226.00			
20		18.97	19.23	5.81	221.44	223.72	43.22	25.88
	Sassafras loam (167 mgm. of nitrogen added)							
Unlimed								
21	Check	29.50			381.16			
22		29.81	29.66		399.56	390.36		
23	Ammonium phosphate	31.58			494.08			
24		38.86	35.22	5.56	459.21	476.65	86.29	51.57
25	Ammonium sulfate	28.96			458.71			
26		31.68	30.32	0.66	506.65	482.68	92.32	55.28
27	Dried blood	32.13			438.20			
28		37.94	35.04	5.38	501.59	469.90	79.54	47.63
29	Cottonseed meal	34.50			474.24			
30		33.39	33.95	4.29	439.29	456.74	66.38	39.75

TABLE 10—(Continued)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	TOTAL NITROGEN RECOVERED	AVERAGE	INCREASE OVER CHECK	PER CENT RECOVERED
	Sassafras loam (167 mgm. of nitrogen added)							
Limed								
		grams	*grams*	*grams*	*mgm.*	*mgm.*	*mgm.*	
31	Check	42.38			470.00			
32		39.42	40.90		481.42	475.71		
33	Ammonium phosphate	lost						
34		42.17	42.17	1.27	596.06	596.06	120.35	72.06
35	Ammonium sulfate	lost						
36		43.06	43.06	2.16	584.11	584.11	109.00	65.27
37	Dried blood	lost						
38		44.47	44.47	3.57	564.03	564.03	88.32	52.89
39	Cottonseed meal	37.37			488.14			
40		42.54	39.96	−0.94	512.77	500.46	24.75	14.82
	Norfolk sand (334 mgm. of nitrogen added)							
Unlimed								
41	Check	8.73			128.88			
42		7.13	7.93		124.11	126.50		
43	Ammonium phosphate	38.74			348.44			
44		38.06	38.40	30.47	338.34	343.39	216.89	64.87
45	Ammonium sulfate	35.05			332.59			
46		37.82	36.44	28.51	343.26	337.93	209.44	62.71
47	Dried blood	27.41			284.22			
48		29.67	28.54	20.61	293.42	288.82	162.32	48.60
49	Cottonseed meal	24.26			264.80			
50		24.60	24.43	16.50	280.54	272.67	146.17	43.76
Limed								
51	Check	11.48			173.65			
52		12.40	11.99		158.41	166.03		
53	Ammonium phosphate	38.12			401.80			
54		38.07	38.10	26.11	397.49	399.65	233.62	69.94
55	Ammonium sulphate	36.28			373.76			
56		37.43	36.86	24.87	377.40	375.58	209.55	62.73
57	Dried blood	27.12			320.13			
58		35.77	31.45	19.46	302.61	311.37	145.34	43.51
59	Cottonseed meal	27.35			300.94			
60		23.33	25.34	13.35	286.32	296.63	127.60	38.20

TABLE 10—(Concluded)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	TOTAL NITROGEN RECOVERED	AVERAGE	INCREASE OVER CHECK	PER CENT RECOVERED
	Sassafras loam (334 mgm. of nitrogen added)							
Unlimed								
		grams	grams	grams	mgm.	mgm.	mgm.	
61	Check	25.33			376.95			
62		23.35	24.34		432.28	404.62		
63	Ammonium phosphate	41.72			611.35			
64		41.72	41.72	17.38	621.84	616.60	211.98	63.46
65	Ammonium sulfate	27.64			670.80			
66		28.74	28.19	3.85	699.97	685.39	280.77	84.06
67	Dried blood	34.68						
68		lost	34.68	10.34	622.17	622.17	217.55	65.13
69	Cottonseed meal	32.62			534.82			
70		34.68	33.65	9.31	566.81	550.82	146.20	43.77
Limed								
71	Check	35.71			546.37			
72		48.07	41.89		708.52	627.45		
73	Ammonium phosphate	50.49			686.62			
74		49.15	49.82	7.93	687.20	686.91	59.46	17.80
75	Ammonium sulfate	50.83			707.09			
76		52.53	51.68	9.79	683.82	695.46	68.01	20.36
77	Dried blood	43.61			616.58			
78		48.15	45.88	3.99	651.42	634.00	6.55	1.96
79	Cottonseed meal	44.87			615.08			
80		46.86	45.87	3.98	643.84	629.46	2.01	0.60

for the organic fertilizers did not seem to be very marked under greenhouse conditions. The third crop in many cases is just as large in the ammonium phosphate or ammonium sulfate pots as in the others.

After removing the three crops, the yields and analyses of which were given in previous tables, the fertilizer applications used at the beginning of the experiment were repeated except that no lime was added. The soils were removed from the pots and the fertilizers mixed with the entire 20 pounds of soil. The yields of the buckwheat and analyses are given in table 11. A residual crop of buckwheat was also grown and the data reported in table 12. Where the crop yield was less than one gram the sample was not analyzed but the proportion of nitrogen was assumed to be 1.7 per cent. The slight error introduced is practically negligible. The buckwheat plants in a few more pots were destroyed by "damping-off" fungi and the yields are not given. The residual crop of buckwheat was so small that it was not considered worth while to plant another crop without additional fertilizer, as was done in the

TABLE 11

Comparative availability of various nitrogenous fertilizers in soil under greenhouse conditions
Fourth crop (buckwheat)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK
	Norfolk sand (167 mgm. of nitrogen added)								
	Unlimed								
		grams	*grams*	*grams*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*
1	Check	3.5			1.41		49.35		
2		1.5	2.50		1.56	1.48	23.40	36.37	
3	Ammonium phosphate	16.2			1.05		170.10		
4		15.7	15.95	13.45	0.98	1.01	153.86	161.98	125.61
5	Ammonium sulfate	13.7			1.14		156.18		
6		15.4	14.55	12.05	1.36	1.25	209.44	182.81	146.44
7	Dried blood	9.0			1.29		116.10		
8		8.4	8.70	6.20	1.21	1.25	101.64	108.87	72.50
9	Cottonsed meal	10.5			1.09		114.45		
10		10.5	10.50	8.00	0.92	1.00	96.60	105.52	69.15
	Limed								
11	Check	5.0			1.35		67.50		
12		4.6	4.80		1.24	1.29	57.04	62.27	
13	Ammonium phosphate	18.1			1.02		184.62		
14		16.7	7.40	12.60	1.13	1.07	188.71	186.66	124.39
15	Ammonium sulfate	16.0			1.07		171.20		
16		16.7	16.35	11.55	1.07	1.07	178.69	174.94	112.67
17	Dried blood	11.7			1.04		121.68		
18		13.9	12.80	8.00	1.07	1.05	148.73	135.20	72.93
19	Cottonseed meal	13.7			0.99		135.63		
20		11.2	12.45	7.65	1.15	1.07	128.80	132.21	69.94
	Sassafras loam (167 mgm. of nitrogen added)								
	Unlimed								
21	Check	1.1			2.26		24.86		
22		1.2	1.15		2.05	2.15	24.60	24.73	
23	Ammonium phosphate	5.4			2.23		120.42		
24		4.0	4.70	3.55	2.35	2.29	94.00	107.21	82.48
25	Ammonium sulfate	4.1			2.60		106.60		
26		2.2	3.15	2.00	2.52	2.56	55.44	81.02	57.29
27	Dried blood	2.6			2.69		69.94		
28		4.6	3.60	2.55	2.33	2.51	107.18	88.56	63.83
29	Cottonseed meal	3.2			2.29		73.28		
30		3.0	3.10	1.95	2.41	2.35	72.30	72.79	48.06

TABLE 11—(Continued)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK
	Sassafras loam (167 mgm. of nitrogen added)								
	Limed								
		grams	grams	grams	per cent	per cent	mgm.	mgm.	mgm.
31	Check	8.0			1.20		96.00		
32		8.7	8.35		1.12	1.16	97.44	96.72	
33	Ammonium phosphate	lost							
34		lost	lost						
35	Ammonium sulfate	lost							
36		18.0	18.00	9.65	1.24	1.24	223.20	223.20	126.48
37	Dried blood	lost							
38		13.7	13.70	5.35	1.26	1.26	172.62	172.62	75.90
39	Cottonseed meal	15.2			1.21		183.92		
40		16.5	15.85	7.50	1.15	1.18	189.75	186.83	90.11
	Norfolk sand (334 mgm. of nitrogen added)								
	Unlimed								
41	Check	0.8			1.79		14.32		
42		0.0	0.40		0.00	1.79	0.00	7.16	
43	Ammonium phosphate	23.1			1.15		265.65		
44		22.7	22.90	22.50	1.20	1.17	272.40	269.02	262.86
45	Ammonium sulfate	14.2			1.84		261.28		
46		15.2	14.70	14.30	1.67	1.75	253.84	257.56	250.40
47	Dried blood	11.8			1.32		155.76		
48		12.9	12.36	11.95	1.31	1.31	168.99	162.37	155.21
49	Cottonseed meal	16.8			1.19		199.92		
50		14.8	15.80	15.40	1.31	1.25	193.88	196.90	189.74
	Limed								
51	Check	3.3			1.31		43.23		
52		4.6	3.90		1.37	1.34	61.65	52.44	
53	Ammonium phosphate	29.5							
54		lost	29.50	25.60	1.13	1.13	333.35	333.35	280.91
55	Ammonium sulfate	24.0			1.21		290.40		
56		25.3	24.65	20.75	1.15	1.18	290.95	290.67	238.23
57	Dried blood	17.6			1.36		239.36		
58		20.2	18.90	15.00	1.26	1.31	254.52	246.94	194.50
59	Cottonseed meal	19.6			1.20		235.20		
60		22.0	20.80	16.90	1.12	1.16	246.40	240.80	188.36

TABLE 11—(Concluded)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK
	Sassafras loam (334 mgm. of nitrogen added)								
Unlimed									
		grams	*grams*	*grams*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*
61	Check	2.1			1.91		40.11		
62		0.6	1.35		2.01	1.96	12.06	26.08	
63	Ammonium phosphate	6.0			2.39		143.40		
64		5.6	5.80	4.45	2.62	2.50	146.72	145.06	118.98
65	Ammonium sulfate	4.2			2.55		107.10		
66		5.2	4.70	3.35	2.74	2.64	142.48	124.79	98.71
67	Dried blood	2.4			2.56		61.44		
68		2.9	2.65	1.30	3.29	2.92	95.41	78.42	52.34
69	Cottonseed meal	5.5			2.51		138.05		
70		5.6	5.55	4.20	2.41	2.46	134.96	136.50	110.42
Limed									
71	Check	7.5			1.24		93.00		
72		9.2	8.35		1.35	1.29	124.20	108.60	
73	Ammonium phosphate	lost							
74		23.5	23.50	15.15	1.27	1.27	298.45	298.45	189.85
75	Ammonium sulfate	26.6			1.26		335.16		
76		31.0	28.80	20.45	1.08	1.17	334.80	334.98	226.38
77	Dried blood	23.0			1.35		310.50		
78		22.4	22.70	14.35	1.27	1.31	284.48	297.49	188.89
79	Cottonseed meal	20.6			1.08		222.48		
80		23.9	22.25	13.90	1.22	1.15	291.58	257.03	148.43

first portion of this experiment. The summarized results for the two crops are given in table 13.

In the following discussion of the results obtained subsequent to the second application of fertilizers to the soil it should be borne in mind that the recovery of nitrogen is probably influenced to some extent, at least, by the previous application of fertilizers. Just to what extent this factor enters in cannot be stated but it is certainly true that in most cases the recoveries of nitrogen during the second stage of the experiment were greater than for the original application. This is in agreement with the work of Lipman and Blair (22) who found that in cylinder experiments the average recoveries of nitrogen from all series for three rotations, covering a period of 15 years, were 34.94, 35.35 and 38.30 per cent, respectively, for the first, second and third rotations. The writer is not inclined to attribute this to the residual effect of the fertilizers since in many cases the last crop on the treated pots was little larger than on the checks, indicating that there is little benefit from any residual nitrogen that

TABLE 12

Comparative availability of various nitrogenous fertilizers in soil under greenhouse conditions

Fifth crop (buckwheat)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK
	Norfolk sand								
	Unlimed								
		grams	*grams*	*grams*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*
1	Check	0.1			1.70		1.70		
2		1.0	0.55		1.67	1.68	16.70	9.20	
3	Ammonium phosphate	0.5			1.70		8.50		
4		0.4	0.45	−0.10	1.70	1.70	6.80	7.65	− 1.55
5	Ammonium sulfate	0.1			1.70		1.70		
6		0.1	0.10	−0.45	1.70	1.70	1.70	1.70	− 7.50
7	Dried blood	1.0			1.78		17.00		
8		0.4	0.70	0.15	1.70	1.74	6.80	11.90	2.70
9	Cottonseed meal	0.5			1.70		8.50		
10		0.5	0.50	−0.05	1.70	1.70	8.50	8.50	− 0.65
	Limed								
11	Check	0.0							
12		0.0	0.0						
13	Ammonium phosphate	0.5			1.70		8.50		
14		0.5	0.50	0.50	1.70	1.70	8.50	8.50	8.50
15	Ammonium sulfate	0.2			1.70		3.40		
16		0.0	0.10	0.10		1.70		1.70	1.70
17	Dried blood	0.3			1.70		5.10		
18		0.5	0.40	0.40	1.70	1.70	8.50	6.80	6.80
19	Cottonseed meal	0.3			1.70		5.10		
20		0.5	0.40	0.40	1.70	1.70	8.50	6.80	6.80
	Sassafras loam								
	Unlimed								
21	Check	2.9			1.68		48.72		
22		2.7	2.80		1.74	1.71	46.98	47.85	
23	Ammonium phosphate	6.1			1.76		107.36		
24		3.5	4.80	2.00	2.11	1.93	73.85	90.60	42.75
25	Ammonium sulfate	2.5			2.32		58.00		
26		4.5	3.50	0.70	2.46	2.39	110.70	84.35	36.50
27	Dried blood	3.2			1.68		53.76		
28		1.8	2.50	−0.30	2.26	1.97	40.68	47.22	− 0.63
29	Cottonseed meal	3.3			2.06		67.98		
30		4.4	3.85	1.05	1.74	1.90	76.56	72.27	24.42

TABLE 12—(Continued)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK
	Sassafras loam								
	Limed								
		grams	grams	grams	per cent	per cent	mgm.	mgm.	mgm.
31 32	Check	1.9 1.7	1.80		1.75 1.60	1.67	33.25 27.20	30.22	
33 34	Ammonium phosphate	lost lost							
35 36	Ammonium sulfate	lost 2.2	2.20	0.40	1.44	1.44	31.68	31.68	1.46
37 38	Dried blood	lost 3.4	3.40	1.60	1.42	1.42	48.28	48.28	18.06
39 40	Cottonseed meal	3.3 2.6	2.95	1.15	1.24 1.55	1.39	40.92 40.30	40.61	10.39
	Norfolk sand								
	Unlimed								
41 42	Check	1.2 2.2	1.70		1.80 1.81	1.80	21.60 39.82	30.71	
43 44	Ammonium phosphate	0.6 0.8	0.70	−1.00	1.70 1.70	1.70	10.20 13.60	11.90	−18.81
45 46	Ammonium sulfate	0.2 0.0	0.10	−1.60	1.70 1.70	1.70	3.40 0.00	3.40	−27.31
47 48	Dried blood	0.2 0.6	0.40	−1.30	1.70 1.70	1.70	3.40 10.20	6.80	−23.91
49 50	Cottonseed meal	0.4 0.5	0.45	−1.25	1.70 1.70	1.70	6.80 8.50	7.65	−23.06
	Limed								
51 52	Check	0.0 0.0	0.00 0.00						
53 54	Ammonium phosphate	1.5 lost	1.50	1.50	1.78	1.78	26.70	26.70	26.70
55 56	Ammonium sulfate	0.4 0.3	0.35	0.35	1.70 1.70	1.70	6.80 5.10	5.95	5.95
57 58	Dried blood	0.6 0.5	0.55	0.55	1.70 1.70	1.70	10.20 8.50	9.35	9.35
59 60	Cottonseed meal	0.2 0.1	0.15	0.15	1.70 1.70	1.70	3.40 1.70	2.55	2.55

TABLE 12--(Concluded)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK
	Sassafras loam								
	Unlimed								
		grams	*grams*	*grams*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*
51	Check	1.0			1.86		18.60		
52		2.4	1.70		1.86	1.86	44.64	31.62	
63	Ammonium phosphate	6.9			2.44		168.36		
64		4.9	5.90	4.20	2.38	2.41	116.62	142.49	110.87
65	Ammonium sulfate	6.5			2.38		154.70		
66		3.5	5.00	3.30	2.52	2.45	88.20	121.45	89.83
67	Dried blood	4.5			2.25		101.25		
68		4.9	4.70	3.00	3.06	2.65	149.94	125.59	93.97
69	Cottonseed meal	5.4			1.54		83.16		
70		4.0	4.70	3.00	2.56	2.05	102.40	92.78	61.16
	Limed								
71	Check	2.7			1.23		33.21		
72		2.5	2.60		1.33	1.28	33.25	33.23	
73	Ammonium phosphate	lost							
74		3.0	3.00	0.40	1.66	1.66	49.80	49.80	16.57
75	Ammonium sulfate	3.4			1.39		47.26		
76		3.0	3.20	0.60	1.73	1.56	51.90	49.58	16.35
77	Dried blood	3.9			1.21		47.19		
78		3.9	3.90	1.30	1.44	1.32	56.16	51.67	18.44
79	Cottonseed meal	3.6			1.55		55.80		
80		3.0	3.30	0.70	1.61	1.58	48.30	52.05	18.82

may be present. A better explanation for the higher recoveries of nitrogen for the second application of fertilizers lies in the depletion of available plant-food. A soil which has plenty of available nitrogen or at least a fairly large amount will not give high recoveries of nitrogen because the crops can get what they need from the soil organic matter. On the other hand, a crop grown on a poor soil will utilize the nitrogen applied very readily because there is no other sufficient supply available.

The summarized results in table 13 for the unlimed Norfolk sand with the lower rate of application show a lower availability for ammonium phosphate than ammonium sulfate, judging from the recovery of nitrogen. This is contrary to the results obtained for the first application of fertilizer. However, the crop yields are higher for ammonium phosphate, again illustrating the point previously brought out that frequently ammonium sulfate produces a smaller crop but with a higher per cent of nitrogen than does ammonium

TABLE 13

Comparative availability of various nitrogenous fertilizers in soil under greenhouse conditions. Summary—Fourth and fifth crops

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	TOTAL NITROGEN RECOVERED	AVERAGE	INCREASE OVER CHECK	PER CENT RECOVERED
	Norfolk sand (167 mgm. of nitrogen added)							
Unlimed								
		grams	*grams*	*grams*	*mgm.*	*mgm.*	*mgm.*	
1	Check	3.6			51.05			
2		2.5	3.05		40.19	45.57		
3	Ammonium phosphate	16.7			178.60			
4		16.1	16.40	13.35	160.66	169.63	124.06	74.28
5	Ammonium sulfate	13.8			157.88			
6		15.5	14.65	11.60	211.14	184.51	138.94	83.19
7	Dried blood	10.0			133.10			
8		8.8	9.40	6.35	108.44	120.77	75.20	45.03
9	Cottonseed meal	11.0			122.95			
10		11.0	11.0	7.95	105.10	114.02	68.45	40.99
Limed								
11	Check	5.0			67.50			
12		4.6	4.80		57.04	62.27		
13	Ammonium phosphate	18.6			193.12			
14		17.2	17.90	13.10	197.21	195.16	132.89	79.57
15	Ammonium sulfate	16.2			174.60			
16		16.7	16.45	11.65	178.69	176.64	114.37	68.48
17	Dried blood	12.0			126.78			
18		14.4	13.20	8.40	157.23	141.50	79.23	47.44
19	Cottonseed meal	14.0			140.73			
20		11.7	12.85	8.05	137.30	138.51	76.24	45.65
	Sassafras loam (167 mgm. of nitrogen added)							
Unlimed								
21	Check	4.0			73.58			
22		3.9	3.95		71.58	72.58		
23	Ammonium phosphate	11.5			227.78			
24		7.5	9.50	5.55	167.85	197.81	125.23	75.00
25	Ammonium sulfate	6.6			164.60			
26		6.7	6.65	2.70	166.14	165.37	92.79	55.56
27	Dried blood	5.8			123.70			
28		6.4	6.10	2.15	147.86	135.78	63.20	37.84
29	Cottonseed meal	6.5			141.26			
30		7.4	6.95	3.00	148.86	145.06	72.48	43.40

TABLE 13—(Continued)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	TOTAL NITROGEN RECOVERED	AVERAGE	INCREASE OVER CHECK	PER CENT RECOVERED
Limed								
		grams	*grams*	*grams*	*mgm.*	*mgm.*	*mgm.*	
31 32	Check	9.9 10.4	10.15		129.25 124.64	126.94		
33 34	Ammonium phosphate	lost						
35 36	Ammonium sulfate	20.2	20.20	10.05	254.88	254.88	127.94	76.61
37 38	Dried blood	17.1	17.10	6.95	220.90	220.90	93.96	56.23
39 40	Cottonseed meal	18.5 19.1	18.80	8.65	224.84 230.05	227.44	100.50	60.18
Norfolk sand (334 mgm. of nitrogen added)								
Unlimed								
41 42	Check	2.0 2.2	2.10		35.92 39.82	37.87		
43 44	Ammonium phosphate	23.7 23.5	23.60	21.50	275.85 286.00	280.92	243.05	72.77
45 46	Ammonium sulfate	14.4 15.2	14.80	12.70	264.68 253.84	259.26	221.29	66.25
47 48	Dried blood	12.0 13.5	12.75	10.65	159.16 175.79	167.47	129.60	38.80
49 50	Cottonseed meal	17.2 15.3	16.25	14.15	206.72 202.38	204.55	166.68	49.90
Limed								
51 52	Check	3.3 4.5	3.90		43.23 61.65	52.44		
53 54	Ammonium phosphate	31.0 lost	31.00	27.10	360.05	360.05	307.61	92.09
55 56	Ammonium sulfate	24.4 25.6	25.00	21.10	297.20 296.05	296.62	244.18	73.11
57 58	Dried blood	18.2 20.7	19.45	15.55	249.56 263.02	256.29	203.85	61.03
59 60	Cottonseed meal	19.8 22.1	20.95	17.05	238.60 248.10	243.35	190.91	57.16

TABLE 13—(Concluded)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	TOTAL NITROGEN RECOVERED	AVERAGE	INCREASE OVER CHECK	PER CENT RECOVERED
Sassafras loam (334 mgm. of nitrogen added)								
Unlimed								
		grams	*grams*	*grams*	*mgm.*	*mgm.*	*mgm.*	
61	Check	3.1			58.71			
62		3.0	3.05		56.70	57.70		
63	Ammonium phosphate	12.9			311.76			
64		10.5	11.70	8.65	263.34	287.55	229.85	68.81
65	Ammonium sulfate	10.7			261.80			
66		8.9	9.70	6.65	230.68	246.24	188.54	56.45
67	Dried blood	6.9			163.69			
68		7.8	7.35	4.30	245.35	204.02	146.32	43.81
69	Cottonseed meal	10.9			221.21			
70		9.6	10.25	7.20	237.36	229.28	171.58	51.37
Limed								
71	Check	10.2			126.21			
72		11.7	10.95		157.47	141.84		
73	Ammonium phosphate	lost						
74		26.5	26.50	15.55	348.25	348.25	206.41	61.80
75	Ammonium sulfate	30.1			382.42			
76		34.0	32.05	21.10	386.70	384.56	242.72	72.67
77	Dried blood	26.9			357.69			
78		26.3	26.60	15.65	340.64	349.16	207.32	62.07
79	Cottonseed meal	24.2			278.28			
80		26.9	25.55	14.60	339.88	309.08	167.24	50.07

phosphate. Dried blood and cottonseed meal were decidedly lower in availability than either of the ammonium fertilizers.

At the higher rate of application of nitrogen in the absence of lime, ammonium phosphate gave nearly double the crop yield that ammonium sulfate did, but only about 6.5 per cent higher recovery of nitrogen. The high per cent of nitrogen in the crop from the ammonium sulfate pots nearly balanced the smaller crop yield. Cottonseed meal gave somewhat better results than dried blood, but both these organic fertilizers were decidedly lower in availability than the chemical fertilizers.

Where lime was applied to the Norfolk sand the crop yield and also the total recovery of nitrogen were always higher with ammonium phosphate than with ammonium sulfate. In this case the percentages of nitrogen in the crops grown from the two fertilizers were practically the same, contrary to the results on the unlimed soils. As shown in a later table ammonium sulfate increases the acidity of the soil to a slightly greater extent than does ammonium

phosphate. This may partially explain the results, but doubtless the differences noted may be attributed largely to the action of the sulfate and phosphate radicals.

The results from the unlimed Sassafras loam with both rates of application are consistent in the sense that the same relative results were obtained with both the high and the low rates of application. In the percentage recovery of nitrogen, ammonium phosphate was first, ammonium sulfate second, cottonseed meal third and dried blood fourth. With one exception the increase in crop yields over the checks was in the same order. With the higher rate of application cottonseed meal gave a slightly larger yield than ammonium sulfate but the difference is so slight that it may be neglected.

So many results were lost at the lower rate of application in the case of the limed Sassafras loam that very little can be said about it. Doubtless the yields would have been comparable with those obtained where the larger amounts of nitrogen were used. As usual, dried blood and cottonseed meal were not as efficient as ammonium sulfate but the difference was not as great here as in the previous results discussed. Both ammonium phosphate results were lost, one through the mistake in the application of the fertilizer and the other as a result of the "damping off" fungi. With the higher rate of application ammonium sulfate gave a larger crop yield and a higher recovery of nitrogen than ammonium phosphate. Dried blood showed unexpectedly good results, giving the same yield as ammonium phosphate and practically the same recovery of nitrogen. Cottonseed meal was somewhat less available than either of the other fertilizers used.

After the removal of the fifth crop from the pots the original fertilizer applications were repeated except that no lime was added. Corn was planted and harvested when about 18 inches high. The dry weights and percentages of nitrogen in the crop are given in table 14.

On the Norfolk sand, whether limed or unlimed, there was no great difference between the results from ammonium sulfate and from ammonium phosphate. Dried blood was usually not quite as efficient as cottonseed meal but both were inferior to the two ammonium salts.

On the Sassafras loam the two organic fertilizers gave larger yields than the chemical fertilizers on the unlimed soil, but were usually not as efficient in the presence of lime. Ammonium sulfate was somewhat more effective than ammonium phosphate, which is partially in contradiction to the previous crops. Possibly the residual effect, if there is one, together with the fact that a different kind of crop was grown, accounts for the difference.

In table 15 a summary is given of the results for the six crops grown on the same soils. In calculating the relative increases in yield of dry matter and the relative recoveries of nitrogen, the results for the two different rates of application are averaged. Ammonium phosphate is then given a value of 100 and the other fertilizers figured on this basis.

In figures 6 and 7 the relative increases in dry matter over the checks and

TABLE 14

Comparative availability of various nitrogenous fertilizers in soil under greenhouse conditions. Sixth crop (corn)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK	PER CENT RECOVERED
	Norfolk sand (167 mgm. of nitrogen added)									
	Unlimed									
		grams	*grams*	*grams*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*	
1	Check	4.3			1.13		48.59			
2	Check	4.2	4.25		1.16	1.15	48.72	48.65		
3	Ammonium phosphate	9.0			1.22	1.24	109.80			
4	Ammonium phosphate	10.1	9.55	5.30	1.25	1.24	126.25	118.02	69.37	41.54
5	Ammonium sulfate	9.0			1.43		128.70			
6	Ammonium sulfate	9.9	9.45	5.20	1.29	1.36	127.71	128.20	79.55	47.63
7	Dried blood	6.5			1.39		90.35			
8	Dried blood	6.6	6.55	2.30	1.53	1.46	100.98	95.66	47.01	28.15
9	Cottonseed meal	6.5			1.39		90.35			
10	Cottonseed meal	8.5	7.50	3.25	1.30	1.35	110.5	100.42	51.77	31.00
	Limed									
11	Check	4.1			1.27		52.07			
12	Check	3.6	3.85		1.37	1.32	49.32	50.69		
13	Ammonium phosphate	11.0	10.00	6.15	1.32	1.39	145.20	138.30	87.61	52.46
14	Ammonium phosphate	9.0			1.46		131.40			
15	Ammonium sulfate	7.7	9.05	5.20	1.41	1.40	108.57	126.56	75.87	45.43
16	Ammonium sulfate	10.4			1.39		144.56			
17	Dried blood	7.0	7.00	3.15	1.51	1.49	105.70	103.95	53.26	31.89
18	Dried blood	7.0			1.46		102.20			
19	Cottonseed meal	8.0	8.45	4.60	1.37	1.34	109.60	112.65	61.96	37.10
20	Cottonseed meal	8.9			1.30		115.70			
	Sassafras loam (167 mgm. of nitrogen added)									
	Unlimed									
21	Check	3.2			1.72		55.04			
22	Check	3.0	3.10		1.78	1.75	53.40	54.22		
23	Ammonium phosphate	4.6			2.03		93.38			
24	Ammonium phosphate	4.2	4.40	1.30	1.93	1.98	81.06	87.22	33.00	19.76
25	Ammonium sulfate	5.5			2.06		113.30			
26	Ammonium sulfate	4.9	5.20	2.10	1.92	1.99	94.08	103.69	49.47	29.60
27	Dried blood	5.3			1.85		98.05			
28	Dried blood	6.0	5.65	2.55	1.82	1.84	109.2	103.62	49.40	29.51
29	Cottonseed meal	5.5			1.88		103.40			
30	Cottonseed meal	5.3	5.40	2.30	1.75	1.82	92.75	98.07	43.85	26.26

TABLE 14—(Continued)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK	PER CENT RECOVERED
	Sassafras loam (167 mgm. of nitrogen added)									
Limed										
		grams	*grams*	*grams*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*	
31	Check	7.0			1.30		91.00			
32		6.4	6.70		1.32	1.31	84.48	87.74		
33	Ammonium phosphate	lost								
34		lost								
35	Ammonium sulfate	lost								
36		12.00	12.00	5.30	1.44	1.44	172.80	172.80	85.06	50.93
37	Dried blood	lost								
38		11.1	11.10	4.40	1.36	1.36	150.96	150.96	63.22	37.85
39	Cottonseed meal	9.0			1.57		141.30			
40		12.0	10.50	3.80	1.43	1.50	171.60	156.45	68.71	41.14
	Norfolk sand (334 mgm. of nitrogen added)									
Unlimed										
41	Check	5.4			1.34		72.36			
42		4.5	4.95		1.30	1.32	58.50	65.43		
43	Ammonium phosphate	16.7			1.53		255.51			
44		15.1	15.90	10.95	1.60	1.57	241.60	248.55	183.12	54.82
45	Ammonium sulfate	14.6			1.78		259.88			
46		18.5	16.55	11.60	1.41	1.60	256.85	258.36	192.93	57.76
47	Dried blood	13.5			1.53		206.55			
48		11.0	12.25	7.30	1.43	1.48	157.30	181.92	116.49	34.87
49	Cottonseed meal	15.0			1.36		204.00			
50		16.5	15.75	10.80	1.32	1.34	217.80	210.90	145.47	43.55
Limed										
51	Check	5.0			1.48		74.00			
52		5.8	5.40		1.26	1.37	73.08	73.54		
53	Ammonium phosphate	17.6	17.60	12.20	1.51	1.51	265.76	265.76	192.22	57.55
54		lost								
55	Ammonium sulfate	17.7			1.47		260.19			
56		18.7	18.20	12.80	1.47	1.47	274.89	267.54	194.00	58.08
57	Dried blood	13.3			1.72		228.76			
58		16.9	15.10	9.70	1.32	1.52	223.08	225.92	152.38	45.62
59	Cottonseed meal	13.7			1.58		216.46			
60		13.3	13.50	8.10	1.41	1.50	187.53	201.99	128.45	38.46

TABLE 14—(Concluded)

Sassafras loam (334 mgm. of nitrogen added)

POT NO.	TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK	NITROGEN	AVERAGE	TOTAL NITROGEN	AVERAGE	INCREASE OVER CHECK	PER CENT RECOVERED
Unlimed										
		grams	*grams*	*grams*	*per cent*	*per cent*	*mgm.*	*mgm.*	*mgm.*	
61	Check	4.0			1.43		57.20			
62		4.4	4.20		1.43	1.43	62.92	60.06		
63	Ammonium phosphate	5.1			2.16		110.16			
64		7.3	6.20	2.00	2.04	2.10	148.92	129.54	69.48	20.80
65	Ammonium sulfate	7.2			1.81		130.32			
66		6.9	7.05	2.85	1.85	1.83	127.65	128.98	68.92	20.63
67	Dried blood	9.7	9.70	5.50	2.03	2.03	196.91	196.91	136.85	40.97
68		lost			..					
69	Cottonseed meal	8.6			1.90		163.40			
70		7.5	8.05	3.85	2.09	2.00	156.75	160.07	100.01	29.94
Limed										
71	Check	5.2			1.26		65.52			
72		5.1	5.15		1.30	1.28	66.30	65.91		
73	Ammonium phosphate	lost								
74		14.9	14.90	9.75	1.50	1.50	223.50	223.50	157.59	47.18
75	Ammonium sulfate	18.5			1.43		264.55			
76		18.0	18.25	13.10	1.46	1.45	262.80	263.67	197.76	59.21
77	Dried blood	14.5			1.64		237.80			
78		16.1	15.30	10.15	1.57	1.61	252.77	245.28	179.37	5[illegible].70
79	Cottonseed meal	12.7			1.58		200.66			
80		13.6	13.15	8.00	1.62	1.60	220.32	210.49	144.58	43.29

the relative recoveries of nitrogen with the four fertilizers are shown diagrammatically for both the Norfolk and Sassafras loam soils. In this case the results for the two different rates of application are shown separately.

Referring to table 15 it will be noted that ammonium phosphate gave appreciably larger increases in dry matter on both the limed and unlimed Norfolk soil than did ammonium sulfate, and very much greater yields than the two organic fertilizers. On the Sassafras loam the crop yields are quite peculiar, ammonium phosphate giving more than twice the increases of ammonium sulfate in the absence of lime, while where lime is present there is a 32 per cent increase in favor of ammonium sulfate.

The relative yields of dry matter are quite interesting when compared with the recoveries of nitrogen. In the presence of lime the fertilizers which gave the greatest increases in crop yields also gave the highest recoveries of nitrogen, as might be expected, but when lime was absent the figures were somewhat different, especially on the Sassafras loam. With ammonium phosphate

TABLE 15

Comparative availability of various nitrogenous fertilizers in soil under greenhouse conditions. Summary—Six crops

Increase in dry weights

Norfolk sand

MGM. OF NITROGEN APPLIED	UNLIMED				LIMED			
	Ammonium phosphate	Ammonium sulfate	Dried blood	Cottonseed meal	Ammonium phosphate	Ammonium sulfate	Dried blood	Cottonseed meal
501 .... (gm)	31.25	28.10	16.06	20.52	33.90	28.67	22.41	18.46
1002 .... (gm)	62.92	52.81	38.56	41.45	65.41	58.77	44.71	38.50
Total ... (gm)	94.17	80.91	54.62	61.97	99.31	87.44	67.12	56.96
Ratio	100.00	85.90	58.00	65.80	100.00	88.00	67.60	57.30
Sassafras loam								
501 .... (gm)	12.41	5.46	10.08	9.59		17.51	14.92	11.52*
1002 .... (gm)	28.03	13.35	20.14	20.36	33.23	43.99	29.79	26.58
Total ... (gm)	40.44	18.81	30.22	29.95				
Ratio	100.00	46.50	74.70	74.60	100.00	132.40	89.60	80.00

Percentage of nitrogen recovered

Norfolk sand

MGM. OF NITROGEN APPLIED	UNLIMED				LIMED			
	Ammonium phosphate	Ammonium sulfate	Dried blood	Cottonseed meal	Ammonium phosphate	Ammonium sulfate	Dried blood	Cottonseed meal
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
501	60.77	62.41	41.30	38.22	65.41	55.12	42.87	36.21
1002	64.15	62.24	40.76	45.74	73.19	64.64	50.05	44.61
Average nitrogen recovery	63.02	62.30	40.94	43.23	70.60	61.47	47.66	41.81
Relative availability	100.00	98.90	64.90	68.60	100.00	87.10	67.50	59.20
Sassafras loam								
501	52.11	46.81	38.33	36.47		64.27	48.99	38.71*
1002	51.02	53.71	49.97	41.69	42.26	50.75	39.24	31.32
Average nitrogen recovery	51.38	51.41	46.09	39.95				
Relative availability......	100.00	100.10	89.70	77.70	100.00	120.10	92.80	74.10

*Incomplete line not included in calculating ratios.

taken as 100, ammonium sulfate showed a relative crop yield of about 44 in one case and 47.6 in another. The yields from dried blood and cottonseed

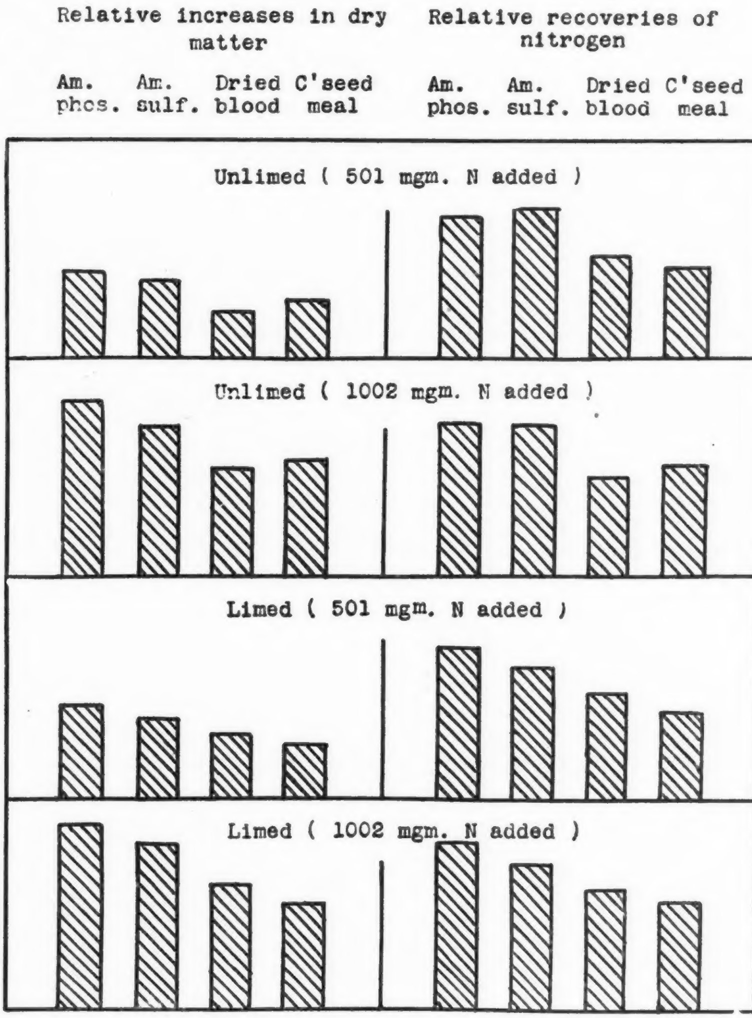

FIG. 6. DIAGRAM SHOWING THE AVAILABILITY OF VARIOUS NITROGENOUS FERTILIZERS IN NORFOLK SAND

meal also were greater than those from ammonium sulfate, but not equal to those from ammonium phosphate. Of course the increases over the checks were quite small on this soil as compared with those on the Norfolk sand, but

nevertheless they are great enough to bring out strikingly that under very acid conditions ammonium sulfate may show a comparatively small crop, but

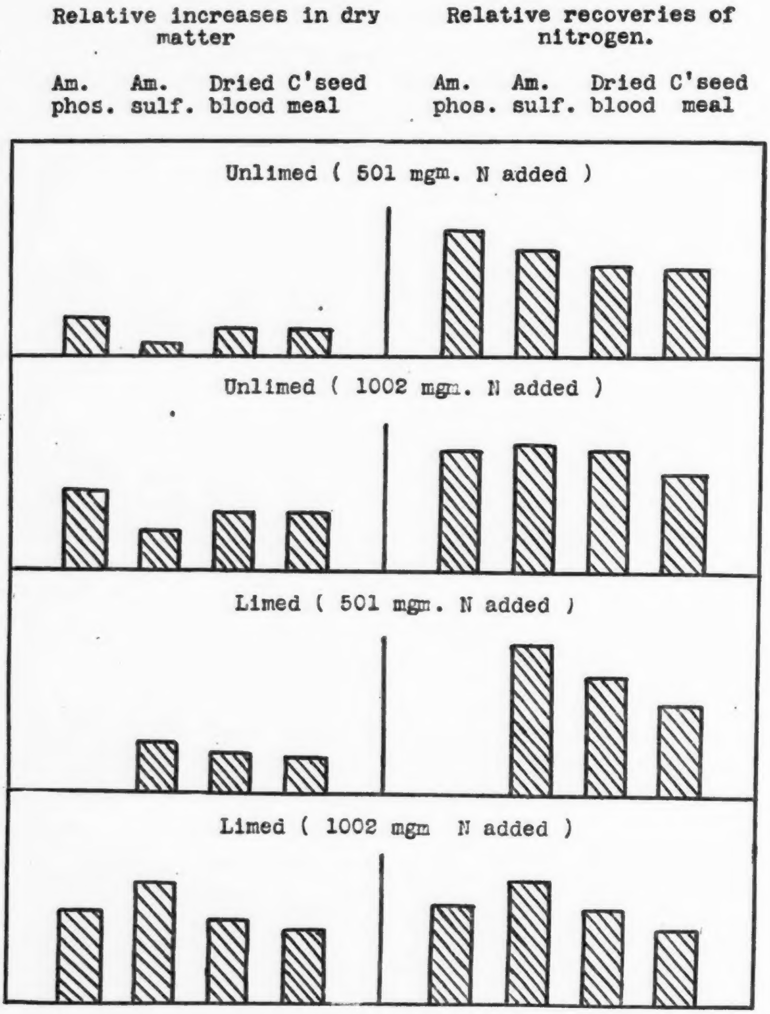

FIG. 7. DIAGRAM SHOWING THE AVAILABILITY OF VARIOUS NITROGENOUS FERTILIZERS IN SASSAFRAS LOAM

on analysis a higher percentage recovery of nitrogen than other fertilizers. It will be remembered that this soil contained a high initial per cent of nitrogen.

Many investigators have recorded the fact that the use of nitrogenous

fertilizers increases the content of nitrogen in the dry matter of plants and necessarily lowers the percentage of carbohydrates. Among these may be mentioned Lipman (21), Beseler and Maercher (1), Ritthausen and Pott (28) and Wagner (34). The latter investigator emphasized the ability of plants to produce large quantities of dry matter with a low nitrogen content when conditions are favorable or a small amount of dry matter with a high nitrogen content when there is an excess of available nitrogen present. The latter condition is quite common where a nitrogenous fertilizer is applied to a soil which is already rich in nitrogen. Adolph Mayer (24) found that while the application of readily-soluble nitrogen may increase the nitrogen content of the plant, there may not necessarily be an increase in protein nitrogen. In an experiment on the relation of lime to the availability of ammonium sulfate, Cook and Allison (4) showed that, while the use of lime in connection with ammonium sulfate may greatly increase the crop yield, the analysis of the crop does not always show a higher recovery of nitrogen in such cases. Similar results to those reported in this thesis were obtained in many cases. While the writers mentioned have shown that the use of the readily available fertilizers, usually sodium nitrate, may increase the per cent of nitrogen in the crop, the enormous increase reported here seems to be wholly out of proportion. In another experiment, the results of which have not yet been published, the writer was able to grow small buckwheat plants in an acid loam soil for a few weeks in the presence of an unusually high percentage of ammonium sulfate, which on analysis showed 16 per cent of nitrogen, while plants grown in a similar soil in the absence of nitrogenous fertilizers showed 0.8 per cent of nitrogen. Evidently the nitrogen represented by this 2000 per cent increase over the check was not present in the plant as protein nitrogen. Whether the same results would have been obtained with ammonium phosphate is, of course, only a matter of conjecture, but the results reported in this thesis indicate that the ammonium phosphate would have behaved in a more normal manner.

As an average of all the conditions, the recoveries of the nitrogen applied to the Norfolk sand were 65.88, 61.10, 43.74 and 41.19, respectively, for ammonium phosphate, ammonium sulfate, dried blood and cottonseed meal. The highest recovery in any case was 73.19 per cent on the limed soil. On the Sassafras loam the average recoveries were 48.46, 50.42, 42.51, and 36.49 per cent for ammonium phosphate, ammonium sulfate, dried blood and cottonseed meal, respectively, the highest being 53.71 per cent on an unlimed soil. In calculating these averages the incomplete set of figures for the smaller application of nitrogen on the limed soil are omitted.

The question naturally arises, what has become of the remainder of the nitrogen applied? No analyses of the soils from the various pots were made to determine if there was more or less nitrogen at the end of the experiment than at the beginning, but this was scarcely necessary for the mere fact that plants would not grow in the pots after removing five crops is in itself sufficient

proof that the supply of nitrogen had decreased very markedly. Even if it were present in an unavailable form it would have soon been made available. Under greenhouse conditions ammonification and nitrification can proceed at a very rapid rate. In explaining the fact that under the most favorable conditions usually not more than 60 per cent of the nitrogen added is recovered in the crop the usual causes set forth have been leaching, fixation in the soil, loss as ammonia, and loss as nitrogen gas. The last two have not been emphasized to any great extent because leaching and fixation by the zeolites and as proteins by the soil microörganisms seemed more plausible.

In this experiment leaching cannot be considered since the plants were grown in pots having no provision for drainage. The second explanation, namely, fixation, does not seem to be of importance, considering that five crops were grown and any nitrogen fixed in the soil, especially as protein, would probably have become available for the plants during the course of the experiment. The most logical conclusion, then, is that nitrogen escaped as free nitrogen gas or as ammonia.

Among the many investigators who have made a study of the loss of ammonia from soils, the following may be mentioned. Hals (7) found that ammonia is lost from loamy soils rich in lime when small quantities of ammonium sulfate are added and the soil is exposed to wind and sun. Wagner (35) attributes the lower efficiency of ammonium sulfate to be due to the escape of ammonia into the air. Kretschiner (13) states that ammonium sulfate should not be used as a top dressing with soils rich in lime. Schäfer-Heide (30) observed that a high lime content and high temperature favored loss of ammonia, especially on light soils. Schreiber (31) conducted pot experiments with oats to determine the effect of calcium carbonate on ammonium sulfate and found that where ammonium sulfate was used as a top-dressing on soils rich in lime decided losses of ammonia occurred. Lemmermann (14) states that the danger of loss of ammonia is small provided the ammonium sulfate is thoroughly incorporated with the soil and the application does not follow liming too closely. Ehrenberg (5) states that loss of ammonia by volatilization is to be feared only in the case of sandy soils which are rich in calcium carbonate, contain little humus and are poor in zeolitic compounds. Even in such soils the loss is not appreciable except at high temperatures and in dry soils containing high contents of ammonia. Lemmerman (15) found that the addition of calcium carbonate to soil in pots reduces the volatilization of ammonium carbonate and increases the absorptive power of the soil for ammonia. Caustic lime exerted an opposite effect.

Numerous studies on the loss of nitrogen gas from soils have been made but only a few references can be given in this discussion. The experiments of Immendorff (10) are significant in that they point to a loss of free nitrogen during the nitrification of ammonium salts. Wilfarth, Römer and Wimmer (36, p. 26) point out that there may be a volatilization of elementary nitrogen during respiration. Lipman and Blair (22) in a discussion of various phases

of the nitrogen problem, state that "there seems to be more or less justification for the assumption made by these investigators (Wilfarth, Römer and Wimmer) for it is quite possible that in the respiration processes there may be destruction, not only of the non-nitrogenous organic compounds, but also of nitrogenous organic compounds, like amino acids or their derivatives. At any rate it has been known for years (2) that there is a loss of nitrogen in the germination of seeds, and the analogy might well be extended to the plant after germination." The same investigators, commenting upon the lower availability of dried blood nitrogen as compared with ammonium sulfate nitrogen state that in the process of decay there are many stages where loss of elementary nitrogen, is liable to occur and the greater the resistance to decay the greater is the danger of loss. Also, in nitrification processes a portion of the nitrogen is set free. The loss with ammonium salts is slight but probably more appreciable with organic combinations.

From the data reported in this paper, obtained with the use of ammonium phosphate, ammonium sulfate, dried blood and cottonseed meal, and in the light of previous work done by various investigators, the writer is inclined to attribute the failure to obtain a complete recovery of the nitrogen applied to the soil in the crops largely to a loss as ammonia or nitrogen gas. Half of the pots received an application of calcium carbonate, yet the recovery of nitrogen from these pots was usually larger than from the unlimed pots; therefore the presence of the lime cannot have been the primary cause of loss of nitrogen. Possibly calcium oxide would have caused a greater loss than occurred on the untreated soils. It would seem that either there is an appreciable loss of ammonia from all soils, both sand and clay, even when kept moist and relatively free from air circulation, or else there is a loss as nitrogen gas from the soil by transpiration. While it has not yet been proved that nitrogen is evolved from plants, there is plenty of evidence strongly indicating that such is the case.

Effect of fertilizers on soil reaction

At the end of a little over one year from the time the experiment on the comparative availability of various nitrogenous fertilizers had been started, and directly following the harvesting of the fifth crop, the lime requirement of the soils in all of the pots was determined. The samples of soil for these analyses were obtained by removing the 20 pounds of soil from the pots, thoroughly mixing and air-drying. The Veitch method for the determination of acidity was used throughout the work. The data are given in table 16, the results being omitted for pots 33, 35 and 37 which, it will be remembered, accidently received an extra application of fertilizer. In other cases fungi injured the crop, but the lime requirements are given regardless of this fact.

In general, the results show that ammonium sulfate and ammonium phosphate increase the acidity to a greater extent than dried blood or cottonseed meal. Usually ammonium sulfate caused a greater acidity than ammonium

TABLE 16

Effect of fertilizers on soil reaction

POT NO.	TREATMENT	MGM. NITROGEN ADDED	MGM. NITROGEN RECOVERED	RESIDUE IN SOIL	LIME REQUIRED AT START. LBS. CaO PER ACRE	LIME REQUIRED AT END. LBS. CaO PER ACRE	INCREASE LBS. PER ACRE	AVERAGE INCREASE LBS. PER ACRE	AVERAGE INCREASE DUE TO FERTILIZERS. LBS. PER ACRE
				Norfolk sand					
					Acid	*Acid*	*Acid*		
1	Check	0	162.39		400	3300	3700		
2		0	142.70		400	3500	3900	3800	
3	Ammonium phosphate	334	394.62	91.92	400	3900	4300		
4		334	380.70	105.84	400	4100	4500	4400	600
5	Ammonium sulfate	334	360.74	125.80	400	4300	4700		
6		334	410.66	75.88	400	4300	4700	4700	900
7	Dried blood	334	314.26	172.28	400	3900	4300		
8		334	310.61	175.93	400	4000	4400	4350	550
9	Cottonseed meal	334	302.00	184.54	400	3300	3700		
10		334	282.80	203.74	400	3500	3900	3800	000
					Alkaline	*Acid*	*Acid*		
11	Check	0	256.47		2240	900	3140		
12		0	229.06		2240	1000	3240	3190	
13	Ammonium phosphate	334	484.06	92.70	2240	1000	3240		
14		334	482.01	94.75	2240	1200	3440	3340	150
15	Ammonium sulfate	334	446.88	129.88	2240	1300	3540		
16		334	439.23	137.53	2240	1300	3540	3540	350
17	Dried blood	334	393.16	183.60	2240	900	3140		
18		334	416.41	160.35	2240	1300	3540	3340	150
19	Cottonseed meal	334	366.73	210.03	2240	1500	3740		
20		334	358.73	218.02	2240	1500	3740	3740	550
				Sassafras loam					
					Acid	*Acid*			
21	Check	0	454.74		2800	6100	3300		
22		0	471.14		2800	6300	3500	3400	
23	Ammonium phosphate	334	721.86	75.08	2800	5900	3100		
24		334	627.06	169.88	2800	6500	3700	3400	000
25	Ammonium sulfate	334	623.31	173.63	2800	6200	3400		
26		334	672.79	124.15	2800	6500	3700	3550	150
27	Dried blood	334	561.90	235.04	2800	6500	3700		
28		334	649.45	147.49	2800	6300	3500	3600	200
29	Cottonseed meal	334	615.50	181.44	2800	6100	3300		
30		334	588.15	208.79	2800	6100	3300	3300	−100

TABLE 16—(Continued)

POT NO.	TREATMENT	MGM. NITROGEN ADDED	MGM. NITROGEN RECOVERED	RESIDUE IN SOIL	LIME REQUIRED AT START. LBS. CaO PER ACRE	LIME REQUIRED AT END. LBS CaO PER ACRE	INCREASE LBS. PER ACRE	AVERAGE INCREASE LBS. PER ACRE	AVERAGE INCREASE DUE TO FERTILIZERS LBS. PER ACRE
	Sassafras loam								
					Alkaline	*Acid*			
31	Check	0	599.25		2240	1800	4040		
32		0	606.06		2240	1600	3840	3940	
33	Ammonium phosphate	334	lost		2240	lost			
34		334	lost		2240	2300	4540	4540	600
35	Ammonium sulfate	334	lost		2240	lost			
36		334	838.99	97.26	2240	3300	5540	5540	1600
37	Dried blood	334	lost		2240	lost			
38		334	784.93	151.72	2240	1700	3940	3940	0000
39	Cottonseed meal	334	712.98	223.67	2240	1500	3740		
40		334	742.82	193.88	2240	1900	4140	3940	000
	Norfolk sand								
					Acid	*Acid*			
41	Check	0	164.80		400	3700	4100		
42		0	163.93		400	3900	4300	4200	
43	Ammonium phosphate	668	624.29	208.07	400	4800	5200		
44		668	624.34	208.02	400	4900	5300	5250	1050
45	Ammonium sulfate	668	597.27	235.09	400	5200	5600		
46		668	597.10	235.26	400	4800	5200	5400	1200
47	Dried blood	668	443.38	388.98	400	4400	4800		
48		668	469.21	363.15	400	4300	4700	4750	550
49	Cottonseed meal	668	471.52	360.84	400	3700	4100		
50		668	482.92	349.44	400	3700	4100	4100	−100
					Alkaline	*Acid*			
51	Check	0	216.88		2240	1300	3540		
52		0	220.06		2240	1300	3540	3540	
53	Ammonium phosphate	668	761.85	124.62	2240	1800	4040		
54		668	lost		2240	1700	3940	3990	450
55	Ammonium sulfate	668	670.96	215.51	2240	2100	4340		
56		668	673.45	213.02	2240	2200	4440	4390	850
57	Dried blood	668	569.69	316.78	2240	1700	3940		
58		668	565.63	320.84	2240	1700	3940	3940	400
59	Cottonseed meal	668	539.54	346.93	2240	1700	3940		
60		668	534.42	352.05	2240	1500	3740	3840	300

TABLE 16—(Concluded)

POT NO.	TREATMENT	MGM. NITROGEN ADDED	MGM. NITROGEN RECOVERED	RESIDUE IN SOIL	LIME REQUIRED AT START. LBS. CaO PER ACRE	LIME REQUIRED AT END. LBS. CaO PER ACRE	INCREASE LBS. PER ACRE	AVERAGE INCREASE LBS. PER ACRE	AVERAGE INCREASE DUE TO FERTILIZERS LBS. PER ACRE
			Sassafras loam						
					Acid	*Acid*			
61	Check	0	435.66		2280	6300	4020		
62		0	488.98		2280	6300	4020	4020	
63	Ammonium phosphate	668	923.11	207.21	2280	6700	4420		
64		668	885.18	245.14	2280	6900	4620	4520	500
65	Ammonium sulfate	668	932.60	197.72	2280	6400	4120		
66		668	930.65	199.67	2280	6600	4320	4220	200
67	Dried blood	668	784.86	345.46	2280	6400	4120		
68		668	lost		2280	6500	4220	4170	150
69	Cottonseed meal	668	756.03	374.29	2280	6400	4120		
70		668	804.17	326.15	2280	6600	4320	4220	200
					Alkaline	*Acid*			
71	Check	0	672.58		2240	1700	3940		
72		0	865.99		2240	1700	3940	3940	
					Alkaline	*Acid*			
73	Ammonium phosphate	668	lost		2240	2500	4740		
74		668	1035.45	402.83	2240	2600	4840	4790	850
75	Ammonium sulfate	668	1089.51	347.77	2240	2800	5040		
76		668	1070.52	366.76	2240	2800	5040	5040	1100
77	Dried blood	668	974.27	463.01	2240	1900	4140		
78		668	992.06	445.22	2240	1700	3940	4040	100
79	Cottonseed meal	668	893.36	543.92	2240	1700	3940		
80		668	983.72	453.56	2240	1800	4040	3990	50

phosphate. The two organic fertilizers showed very different behavior under different conditions. Sometimes dried blood showed a greater development of acid than cottonseed meal and again the reverse was true, or perhaps no acidity developed at all above that in the checks.

Averaging the results of all determinations we find that the increase in lime requirement over the checks due to ammonium sulfate was 793.7 pounds of CaO, with ammonium phosphate 525 pounds, with dried blood 262.5 pounds, and with cottonseed meal 112.5 pounds. These results are about what would be expected and are in agreement with other work as far as ammonium sulfate and the organic forms of nitrogen are concerned. As far as the writer knows no data have been reported for ammonium phosphate. It is impossible in this paper to take up a discussion of the acidity work which has been carried out with the other fertilizers.

Comparative availability of the nitrogen in sodium nitrate, "Ammo-Phos," water-soluble "Ammo-Phos," and water-insoluble "Ammo-Phos" in sand cultures

Ten-pound portions of very poor red sand were weighed out into pots and the various fertilizers added, including sodium nitrate, "Ammo-Phos," and water-soluble and water insoluble "Ammo-Phos." Enough of each of these was applied so that each treated pot contained 100 mgm. of nitrogen. All pots received 1 gm. of KCl and 10 gm. of calcium carbonate together with enough acid phosphate to make the total phosphorus equal to that in water-soluble "Ammo-Phos." The dry weights of the buckwheat are given in table 17.

TABLE 17

Availability of different portions of "Ammo-Phos"

TREATMENT	YIELD	AVERAGE	INCREASE OVER CHECK
	grams	*grams*	*grams*
Check	4.0 3.1	3.55	
"Ammo-Phos"	14.9 lost	14.90	11.35
Water-soluble "Ammo-Phos"	14.5 14.0	14.25	10.70
Water-insoluble "Ammo-Phos"	lost 13.8	13.80	10.25
Sodium nitrate	15.0 13.5	14.25	10.70

From table 17 it will be noticed that there was practically no difference in the availability of the various forms of nitrogen. For some unknown reason "Ammo-Phos" was slightly better than sodium nitrate and even better than the water-insoluble portion of "Ammo-Phos." The water insoluble "Ammo-Phos" was nearly as good as the other forms of nitrogen, the difference being practically within experimental error.

General review and discussion of nitrogen availability experiments

The pot experiments have shown rather definitely the availability of the ammonium phosphate fertilizer as compared with other common nitrogenous fertilizers. It has been brought out that in general the nitrogen in ammonium phosphate gives at least as good results as that in ammonium sulfate and often slightly higher yields under greenhouse conditions. In the one experiment in sand in the greenhouse, sodium nitrate produced about the same increase in yield as ammonium phosphate. It is to be regretted that sodium

nitrate was not also included in the greenhouse soils experiment, but by comparing the results obtained when ammonium sulfate and the organic fertilizers were used, with the extensive experiments of other investigators, we gain a fair idea of the relative value of the nitrogen in ammonium phosphate as compared with that in the other common fertilizers. Since ammonium phosphate gives at least as good results as ammonium sulfate, then by considering the latter in relation to sodium nitrate we can gain a fair idea of what could be expected if ammonium phosphate were directly compared with sodium nitrate.

While it might be desirable to include a bibliography of the question of availability at this point, it is impossible to do so for want of space. However, the writer has reviewed the literature rather thoroughly and as a general summary it may be stated that nitrate nitrogen usually gives the best results, ammonia nitrogen ranks second, following by calcium cyanamid and the various organic fertilizers. The data reported in this paper are in general agreement with the average results of other investigators although, of course, ammonium phosphate was not included in their availability experiments.

The work of the various research men has shown better results for sodium nitrate and ammonium sulfate than for the organic form of nitrogen, but there is wide disagreement when we come to contrast ammonium sulfate and sodium nitrate. Some crops were found to prefer ammonia and others nitrate, but the soil and weather conditions are just as important as the crop or more so. Almost invariably the value of ammonium sulfate was relatively higher in wet seasons, while sodium nitrate was more or less independent of moisture, within certain limits, of course. Lime also favors ammonia nitrogen because it allows nitrification to proceed more rapidly through its neutralization of the acids present. Usually early spring applications were more effective than later applications. Several writers have cautioned against the use of large amounts of ammonium salts.

From the standpoint of ammonium phosphate any availability experiments which include ammonium sulfate are important since we can reasonably predict that the phosphate salt will behave in a similar manner to ammonium sulfate and acid phosphate. The data of this thesis for the most part substantiate this assumption. Perhaps the salt will give slightly better results than ammonium sulfate because there is no sulfate radical left in the soil to increase the acidity.

Comparative availability of various phosphate fertilizers in soil under greenhouse conditions

The procedure followed for this experiment was practically a duplication of that used in the nitrogen availability experiment reported in tables 7 to 15, except that phosphorus was the limiting factor instead of nitrogen. The same soils, namely, Norfolk sand and Sassafras loam were chosen. The pots

held only 10 pounds of soil. The fertilizers applied in addition to ammonium phosphate were acid phosphate (17.82 per cent P_2O_5), basic slag (19.04 per cent P_2O_5) and Tennessee raw rock phosphate (31.41 per cent P_2O_5). The rates of application were 0.5 gm. of acid phosphate to one-half of the pots and 1.0 gm. to the remainder, equivalent amounts of phosphorus being added for all treatments. Each pot received 1.3 gm. of potassium chloride. Three grams of ammonium sulfate also were added to all except the ammonium phosphate pots, in which case allowance was made for the nitrogen in the fertilizer. Half of the pots were limed and half left unlimed, as was done in the previous availability experiment. Three crops of buckwheat were grown in all of the pots but only one application of fertilizer was made. The dry weights of the plants are given in table 18 together with the average results for the three crops.

It will be noticed from the table that a few of the duplicate determinations do not agree as closely as might be desired. This is largely explained by the fact that the seed on these pots was not as good as it should have been. A few pots did not have as many plants as the others and consequently did not show quite as large a yield as would otherwise have been the case. However, it will be observed that usually when the yield of the first crop was low the yields for the next two crops tend to even up the differences and the final averages show reasonably close agreement for the duplicate pots. On the unlimed Sassafras loam the agreement between the duplicate treatments was not always close but this was due to the high acidity of the soil. When the fertilizers were added the increased amount of soluble salts applied only served to increase further the injury of the acids already present. Some of the plants on these pots were dead when harvested. None of the increases over the checks were very large, and for this reason it is impossible to draw any sharp distinctions in the availability of the phosphorus of the different fertilizers. The soils themselves contained practically all of that element needed for ordinary crop growth.

The unlimed Norfolk sand at the lower rate of application showed practically no difference in the availability of the phosphorus in ammonium phosphate, acid phosphate and basic slag. The yield from raw rock phosphate was slightly below the others. At the higher rate of application on this soil the yields were less than with the smaller amount of phosphorus present. Doubtless the higher concentration of salts in these pots was injurious.

Where lime was added to the Norfolk sand the yields were much larger than in the absence of lime, but the effect of the various phosphorus-containing fertilizers is negligible in this case. They probably increased the availability of the phosphorus in the soil. In some cases the addition of the fertilizers actually decreased the yield slightly, but the differences are within experimental error.

On the unlimed Sassafras loam at the lower rate of application acid phosphate showed the highest availability, ammonium phosphate second, and the

TABLE 18

Availability of phosphate fertilizers under greenhouse conditions

TREATMENT	FIRST CROP		SECOND CROP		THIRD CROP		AVERAGE		
	Weight	Average	Weight	Average	Weight	Average	Weight	Average	Increase over check
					Norfolk sand (86.1 mgm. of P_2O_5 added)				
Unlimed									
	grams	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*
Check	23.6		8.5		1.3		33.4		
	22.2	22.90	3.1	5.80	1.2	1.25	26.5	29.95	
Ammonium phosphate	30.0		8.8		2.5		41.3		
	26.4	28.20	7.4	8.10	1.6	2.05	35.4	38.35	8.40
Acid phosphate	25.0		10.0		1.2		36.2		
	25.5	25.25	14.0	12.00	1.4	1.30	40.9	38.55	8.60
Basic slag	26.0		11.5		1.5		39.0		
	20.4	23.20	14.2	12.85	1.4	1.45	35.6	37.30	7.35
Raw rock phosphate	21.5		12.3		1.4		35.2		
	27.6	24.55	5.8	9.05	2.5	1.95	35.9	35.55	5.60
Limed									
Check	19.5		24.9		2.0		46.4		
	20.1	19.80	19.2	22.05	6.9	4.45	46.2	46.30	
Ammonium phosphate	27.0		11.8		4.0		42.8		
	26.7	26.85	10.3	11.05	3.8	3.90	40.8	41.80	−4.50
Acid phosphate	25.0		17.0		2.0		44.0		
	24.5	24.75	20.2	18.60	1.8	1.90	46.5	45.25	−1.05
Basic slag	26.4		15.7		2.3		44.4		
	21.0	23.70	23.0	19.35	1.6	1.95	45.6	45.00	−1.30
Raw rock phosphate	28.5		21.0		4.7		54.2		
	20.7	24.60	19.7	20.35	1.8	3.25	42.2	48.20	1.90
					Sassafras loam (86.1 mgm. of P_2O_5 added)				
Unlimed									
Check	6.0		5.0		2.2		13.2		
	11.3	8.65	3.5	4.25	1.9	2.05	16.7	14.95	
Ammonium phosphate	12.7		6.0		2.1		20.8		
	16.3	14.54	4.7	5.35	1.9	2.00	22.9	21.85	6.90
Acid phosphate	18.0		6.0		1.7		25.7		
	17.0	17.50	5.9	5.95	1.8	1.75	24.7	25.20	10.25
Basic slag	5.5		8.4		2.6		16.5		
	14.0	9.75	5.4	6.90	1.5	2.05	20.9	18.70	3.75
Raw rock phosphate	14.0		4.0		1.3		19.3		
	9.6	11.80	4.0	4.00	2.1	1.70	15.7	17.50	2.55

TABLE 18—(Continued)

TREATMENT	FIRST CROP		SECOND CROP		THIRD CROP		AVERAGE		
	Weight	Average	Weight	Average	Weight	Average	Weight	Average	Increase over check
Limed									
	grams	grams	grams	grams	grams	grams	grams	grams	grams
Check	13.8 12.4	13.10	9.5 7.1	8.30	6.9 6.5	6.70	30.2 26.0	28.10	
Ammonium phosphate	15.0 19.2	17.0	14.5 14.5	14.50	8.1 6.9	7.50	37.6 40.6	39.10	11.00
Acid phosphate	16.0 16.5	16.25	15.4 15.1	15.25	9.1 7.1	8.10	40.5 38.7	39.60	11.50
Basic slag	16.0 11.2	13.60	17.7 23.4	20.55	6.7 6.9	6.80	40.4 41.5	40.95	12.85
Raw rock phosphate	10.4 7.8	9.10	16.0 15.6	15.80	7.5 7.3	7.40	33.9 30.7	32.30	4.20
Norfolk sand (172.2 mgm. of P_2O_5 added)									
Unlimed									
Check	23.6 22.2	22.90	8.5 3.1	5.80	1.3 1.2	1.25	33.4 26.5	29.95	
Ammonium phosphate	26.8 21.7	24.25	6.5 13.1	9.80	1.5 1.1	1.30	34.8 35.9	35.35	5.40
Acid phosphate	23.6 21.0	22.30	10.6 9.0	9.80	1.8 1.0	1.40	36.0 31.0	33.50	3.55
Basic slag	21.4 21.3	21.35	5.7 13.6	9.65	1.5 1.5	1.50	28.6 36.4	32.50	2.55
Raw rock phosphate	19.5 16.5	18.00	16.8 13.0	9.90	2.5 2.5	2.50	38.8 32.0	35.4	5.45
Limed									
Check	19.5 20.1	19.80	24.9 19.2	22.05	2.0 6.9	4.45	46.4 46.2	46.30	
Ammonium phosphate	18.4 22.5	20.45	25.3 22.0	23.65	2.2 2.5	2.35	45.9 47.0	46.45	0.15
Acid phosphate	23.2 15.4	19.30	18.9 25.7	22.30	5.3 3.9	4.60	47.4 45.0	46.20	−0.10
Basic slag	22.5 18.5	20.50	24.5 23.9	24.20	2.5 2.2	2.35	49.5 44.6	47.05	0.75
Raw rock phosphate	16.0 14.2	15.10	21.2 25.7	23.45	3.0 6.0	4.50	40.2 45.9	43.05	−3.25

TABLE 18—(Concluded)

TREATMENT	FIRST CROP Weight	FIRST CROP Average	SECOND CROP Weight	SECOND CROP Average	THIRD CROP Weight	THIRD CROP Average	AVERAGE Weight	AVERAGE Average	AVERAGE Increase over check
Sassafras loam (172.2 mgm. of P_2O_5 added)									
Unlimed									
	grams	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*
Check	6.0 11.3	8.65	5.0 3.5	4.25	2.2 1.9	2.05	13.2 16.7	14.95	
Ammonium phosphate	10.0 9.8	9.90	15.4 9.4	12.40	1.7 1.3	1.50	27.1 20.5	23.8	8.85
Acid phosphate	20.7 16.8	18.75	5.5 8.9	7.20	2.6 1.4	2.00	28.8 27.1	27.95	13.00
Basic slag	9.6 13.9	11.25	13.0 12.0	12.50	1.3 1.9	1.60	23.9 27.8	25.85	10.90
Raw rock phosphate	15.0 10.6	12.80	3.7 5.8	4.75	1.2 1.5	1.35	19.9 17.9	18.9	3.95
Limed									
Check	13.8 12.4	13.10	9.5 7.1	8.30	6.9 6.5	6.70	30.2 26.0	28.10	
Ammonium phosphate	14.1 14.3	14.20	17.7 23.9	20.80	8.2 6.5	7.35	40.0 44.7	42.35	14.25
Acid phosphate	14.8 14.0	14.40	18.6 23.2	20.90	5.7 5.8	5.75	39.1 43.0	41.05	12.95
Basic slag	10.0 12.6	11.30	17.0 20.4	18.70	8.2 5.9	7.05	35.2 38.9	37.05	8.95
Raw rock phosphate	9.8 10.5	10.15	14.1 14.2	14.15	6.8 8.0	7.40	30.7 32.7	31.70	3.60

other two fertilizers third and fourth. With larger amounts of phosphorus present the order of availability was acid phosphate, basic slag, ammonium phosphate and raw rock phosphate. As previously stated, the high acidity in these pots greatly injured the plants. The results indicate that acid phosphate, as has been previously shown, does not increase the acidity and hence gives comparatively good results in this acid soil. Basic slag is also beneficial for the same reason. Ammonium phosphate has been shown to increase the acidity somewhat and hence shows a lower availability than acid phosphate.

On the other hand, in the presence of lime the availability of ammonium phosphate and acid phosphate was practically the same with both rates of application. In one case basic slag was slightly superior to all the other fertilizers, and in the other it was not quite as good as ammonium phosphate or acid phosphate. The sample of basic slag used in this experiment had been used in previous pot experiments at the New Jersey Agricultural Experi-

ment Station and had shown exceptionally good results. No doubt the ordinary commercial basic slag would have shown lower results than are here recorded. Raw rock phosphate proved to be relatively unavailable, as has been repeatedly shown.

In general, this experiment indicates that on the basis of the phosphorous present, ammonium phosphate is of the same availability as acid phosphate. If the soil is acid and low in phosphorus the addition of ground limestone will probably increase the availability of ammonium phosphate, but if the soil is acid and high in phosphorus the availability may be actually decreased, or apparently so, by making conditions favorable for the utilization of the phosphorus already in the soil rather than that added.

TABLE 19

Availability of phosphate fertilizers in quartz sand

TREATMENT	FIRST CROP WEIGHT	SECOND CROP WEIGHT	TOTAL WEIGHT	AVERAGE	INCREASE OVER CHECK
	grams	*grams*	*grams*	*grams*	*grams*
Check	2.8	2.1	4.9		
	3.0	2.6	5.6	5.25	
Ammonium phosphate	13.0	2.5	15.5		
	12.4	2.5	14.9	15.20	9.95
Acid phosphate	13.0	2.0	15.0		
	12.0	2.5	14.5	14.75	9.50
Raw rock phosphate	5.0	3.3	8.3		
	5.5	2.9	8.4	8.35	3.10

Comparative availability of various phosphate fertilizers in quartz sand under greenhouse conditions

For this experiment 10-pound portions of quartz sand were weighed out into pots and 1 gm. of K_2SO_4, 0.3 gm. of $MgSO_4$, 0.15 gm. of $Fe_2(SO_4)_3$ and 5 gm. of $CaCO_3$ added to each in addition to phosphorus in the form of ammonium phosphate, acid phosphate or raw rock phosphate. In each case the amount of phosphorus present was equivalent to that in 2 gm. of acid phosphate. The acid phosphate analyzed 15 per cent P_2O_5 and the raw rock phosphate 31.41 per cent. All pots except those containing ammonium phosphate received 1.3 gm. of ammonium sulfate; in the latter case allowance was made for the nitrogen present in the fertilizer. Two crops of buckwheat were grown following the one application of fertilizers. The dry weights of the plants are given in table 19.

From the results of the experiment in quartz sand we may say that there is practically no difference between the fertilizing value of phosphorus in ammonium phosphate and that in acid phosphate. The slight difference

noted here is in favor of ammonium phosphate. Raw rock phosphate is about one-third as efficient as the other two fertilizers.

GERMINATION TESTS

While the experiments reported above had not indicated that ammonium phosphate would injure the growth of young plants it seemed desirable to make some direct tests to determine what crops are most easily injured by high concentrations of the salt; also how much can be safely applied to various soil types; the relative toxicity as compared with other common nitrogenous fertilizers; and finally, methods of application and general treatment that will lessen the injurious effect of a given application or enable larger applications to be made safely. Knowing the composition and method of preparation of the commercial ammonium phosphate it did not seem likely that it would

TABLE 20

Effect of ammonium phosphate on germination in a loam soil. Percentage germination

AMMONIUM PHOSPHATE APPLIED	WHEAT	COWPEAS	BUCKWHEAT	RAPE	BARLEY	OATS	CORN	VETCH
grams								
0.000	78.5	100.0	100.0	100.0	100.0	100.0	100.0	80.0
0.025	71.4	75.0	100.0	85.7	100.0	85.7	100.0	50.0
0.050	64.3	62.5	100.0	92.9	85.7	100.0	100.0	60.0
0.100	85.7	87.5	90.0	71.4	100.0	78.5	100.0	60.0
0.250	78.5	50.0	100.0	100.0	92.9	100.0	100.0	50.0
0.500	71.4	50.0	100.0	92.9	92.9	100.0	100.0	70.0
1.000	78.5	50.0	100.0	85.7	85.7	100.0	100.0	70.0
2.500	92.9	50.0	90.0	64.3	100.0	100.0	100.0	70.0
5.000	64.3	0.0	100.0	7.1	85.7	92.9	100.0	10.0

produce any greater injury than the pure mono-ammonium phosphate salt. That this assumption was found to be correct is shown by data given later, therefore, even though the commercial ammonium phosphate was used throughout the germination tests, it may be safely assumed that practically the same results would have been obtained with the pure salt.

The method adopted in the experimental work was to weigh out into tumblers 200 gm. of soil, in some cases moist and in other cases air-dried. The fertilizer was either mixed with the entire 200 gm. of soil or applied in a layer at some portion of the soil mass, frequently in direct contact with the seeds. The experiments were carried out at room temperature and at optimum moisture content for the various soils used. The details of the procedure used for each of the different experiments are given as these are discussed. The germination tests were always carried out in duplicate, with the exception of the first experiment, but for the purpose of conserving space only the averages are given in the following tables.

Effect of ammonium phosphate in various concentrations on different crops in a loam soil

This experiment was intended to serve merely as a preliminary trial to determine the approximate concentration required to injure the germination of various seeds. Moist loam soil was obtained directly from the field and weighed out in 200-gm. portions into tumblers. The fertilizer was mixed with the entire sample of soil. In the case of corn and cowpeas eight seeds were planted per tumbler, ten of buckwheat and vetch and fourteen of all the remainder. The results are given in table 20 in terms of percentage germination.

It will be noticed that the results are somewhat erratic, in many cases due to lack of duplicate tumblers for each rate of application, the small number of seeds used, and in some cases the poor vitality of the seeds. The results as a whole, however, do establish in a general way the point at which toxic effects on germination begin to show. These toxic points, as shown by the figures, agreed rather closely with the actual appearance of the plants.

When the plants were older some of them began to die, even in concentrations below 1000 mgm. At the end of three weeks the cowpeas were dying in the 500-mgm. tumbler, buckwheat in the 250-mgm. tumbler, and corn in the 500-mgm. tumbler. There is but little doubt that the greatest injury of the fertilizer applied under field conditions would not be to germination, itself, but rather to the young plants after they are a few inches in height.

Effect of ammonium phosphate, ammonium sulfate, and acid phosphate on corn, wheat, and soybeans in a loam soil

This experiment was carried out in the same manner as the one previously discussed except that an air-dried Penn loam soil was used and 12 seeds planted in each tumbler. The fertilizer was thoroughly mixed with the entire 200 gm. of soil. The corn was cut 30 days and the wheat and soybeans 40 days, after the time of planting, and the weight taken. In the case of ammonium sulfate the same amount of nitrogen was applied as in the ammonium phosphate tumblers. Likewise, the acid phosphate applications were based on the amount of phosphoric acid in the ammonium phosphate. In another series of tumblers the acid phosphate and ammonium sulfate were combined, giving a mixture with the same amount of nitrogen and phosphorus as is present in ammonium phosphate. The summarized results are given in table 21, and a portion of the data shown diagrammatically in figure 8.

A glance at the figures shows that the diminution in the yield of green matter was rather gradual as the applications of the two fertilizers, ammonium phosphate and ammonium sulfate, increased. At the lower rates of application there was a stimulation in the growth of corn and wheat due to the plant-food added, and then at higher concentrations the decline was gradual, many

of the plants having died before harvesting. Acid phosphate showed a marked stimulation up to amounts equivalent to ·4 gm. of ammonium phosphate per tumbler, and then a sudden drop. Where acid phosphate and ammonium

TABLE 21

Effect of fertilizers on the germination and early growth of corn, wheat and soybeans in a loam soil

TREATMENT (GM.)	AVERAGE GERMINATION			AVERAGE WEIGHT		
	Corn	Wheat	Soy-beans	Corn	Wheat	Soy-beans
	per cent	*per cent*	*per cent*	*grams*	*grams*	*grams*
Check	100.0	95.8	95.8	6.9	0.58	11.5
Ammonium phosphate 0.250	100.0	95.8	100.0	7.5	0.89	9.6
Ammonium phosphate 0.500	100.0	83.3	95.8	8.6	0.90	9.1
Ammonium phosphate 1.000	100.0	91.7	54.2	7.3	0.94	2.3
Ammonium phosphate 2.000	100.0	87.5	95.8	5.2	0.92	3.2
Ammonium phosphate 3.000	95.8	66.6	33.3	4.6	0.60	0.2
Ammonium phosphate 4.000	100.0	91.7	45.8	2.8	0.44	0.0
Ammonium phosphate 5.000	95.8	83.3	45.8	2.8	0.24	0.0
Ammonium sulfate 0.131	100.0	95.8	95.8	9.0	1.00	10.5
Ammonium sulfate 0.263	100.0	95.8	100.0	8.7	0.95	9.3
Ammonium sulfate 0.526	100.0	91.7	95.8	7.6	0.91	8.7
Ammonium sulfate 1.051	100.0	100.0	83.3	6.0	1.02	6.6
Ammonium sulfate 1.577	100.0	75.0	37.5	5.6	0.63	1.1
Ammonium sulfate 2.102	95.8	79.2	37.5	3.2	0.46	0.0
Ammonium sulfate 2.628	100.0	62.5	25.0	2.4	0.14	0.0
Ammonium sulfate 0.131+acid phosphate 0.719	100.0	100.0	91.7	8.9	1.24	8.1
Ammonium sulfate 0.263+acid phosphate 1.438	100.0	91.7	83.3	7.5	0.88	8.3
Ammonium sulfate 0.526+acid phosphate 2.875	100.0	87.5	100.0	6.8	0.80	9.2
Ammonium sulfate 1.051+acid phosphate 5.750	95.8	95.8	83.3	4.6	0.93	3.6
Ammonium sulfate 1.577+acid phosphate 8.625	100.0	100.0	45.8	4.3	0.38	0.0
Ammonium sulfate 2.102+acid phosphate 11.501	95.8	100.0	41.6	2.7	0.26	0.0
Ammonium sulfate 2.628+acid phosphate 14.386	95.8	87.5	25.0	1.7	0.15	0.0
Acid phosphate 0.719	100.0	100.0	87.5	7.4	1.13	8.2
Acid phosphate 1.438	100.0	95.8	83.3	8.1	1.19	8.5
Acid phosphate 2.875	100.0	91.7	79.2	7.6	1.03	9.6
Acid phosphate 5.750	100.0	79.2	91.7	7.4	1.07	8.6
Acid phosphate 8.625	100.0	95.8	83.3	6.4	1.18	7.8
Acid phosphate 11.501	25.0	16.6	8.3	0.2	0.00	0.0
Acid phosphate 14.386	0.0	8.3	4.2	0.0	0.00	0.0

sulfate were used together the growth more nearly corresponded to that of ammonium phosphate or ammonium sulfate when used alone. The results with soybeans showed the same trend, except as already stated, the fertilizers were much more toxic and showed less tendency to stimulate. In general,

ammonium phosphate is slightly less toxic than ammonium sulfate used in combination with acid phosphate for corn and wheat and more

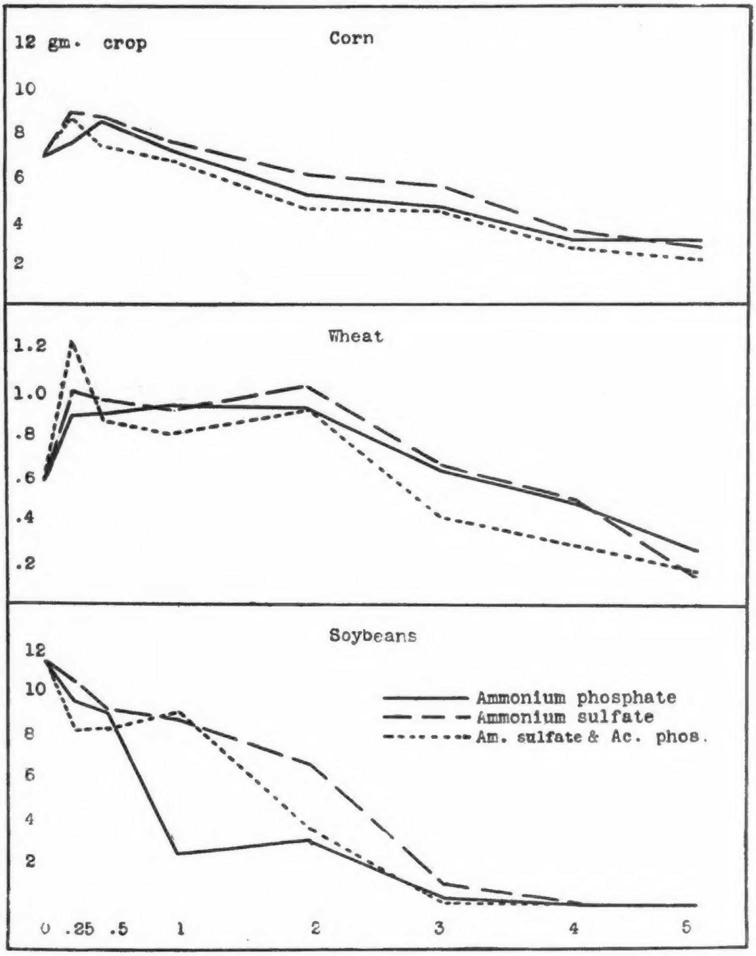

FIG. 8. DIAGRAM SHOWING THE EFEECT OF FERTILIZERS ON THE EARLY GROWTH OF PLANTS IN A LOAM SOIL

(Figures represent grams of ammonium phosphate. Ammonium sulfate applications contained equivalent amounts of nitrogen.)

toxic than ammonium sulfate used singly. For soybeans ammonium phosphate was more toxic than ammonium sulfate alone or in combination with acid phosphate.

TABLE 22

Effect of various nitrogenous fertilizers, alone and in combination, on the germination and growth of corn in a limed and an unlimed loam soil

TREATMENT		0 MGM. NITROGEN	56 MGM. NITROGEN	111 MGM. NITROGEN	223 MGM. NITROGEN	334 MGM. NITROGEN	446 MGM. NITROGEN	557 MGM. NITROGEN
Limed								
Check	Germination (per cent)	100.0						
	Weight (gram)	6.3						
Ammonium phosphate	Germination		87.5	91.7	100.0	91.7	100.0	70.8
	Weight		5.6	6.3	5.0	8.3	6.7	3.5
Ammonium sulfate	Germination		83.3	79.2	87.5	91.7	91.7	58.3
	Weight		5.7	5.4	4.7	5.2	3.5	9.9
Ammonium sulfate + acid phosphate	Germination		87.5	100.0	100.0	100.0	100.0	87.5
	Weight		5.4	6.4	6.6	8.1	6.5	3.0
Sodium nitrate + acid phosphate	Germination		100.0	87.5	87.5	75.0	66.6	4.2
	Weight		7.2	6.1	4.1	1.2	1.5	0.0
Unlimed								
Check	Germination	87.5						
	Weight	7.3						
Ammonium phosphate	Germination		91.7	87.5	95.8	91.7	100.0	91.7
	Weight		10.0	9.2	3.9	3.0	2.4	0.8
Ammonium sulfate	Germination		91.7	79.2	87.5	91.7	91.7	66.6
	Weight		10.8	7.9	3.6	3.0	1.0	1.2
Ammonium sulfate + acid phosphate	Germination		100.0	91.7	91.7	91.7	100.0	87.5
	Weight		10.1	8.7	3.3	2.6	1.2	1.8
Sodium nitrate + acid phosphate	Germination		100.0	100.0	91.7	70.8	50.0	20.8
	Weight		11.5	8.6	4.5	0.9	0.5	0.0

		0 MGM. NITROGEN	111 MGM. NITROGEN	223 MGM. NITROGEN	446 MGM. NITROGEN	670 MGM. NITROGEN	893 MGM. NITROGEN	1115 MGM. NITROGEN
Limed								
Check	Germination	100.0						
	Weight	6.3						
Ammonium phosphate + ammonium sulfate	Germination		91.7	95.8	91.7	95.8	58.3	41.6
	Weight		7.0	5.3	5.5	3.6	0.4	0.5
Ammonium phosphate + sodium nitrate	Germination		95.8	79.2	83.3	75.0	54.2	0.0
	Weight		7.3	2.9	2.6	0.5	0.2	0.0
Ammonium sulfate + acid phosphate	Germination		83.3	100.0	100.0	100.0	66.6	20.8
	Weight		5.0	5.8	5.7	2.5	0.5	0.0
Unlimed								
Check	Germination	87.5						
	Weight	7.3						
Ammonium phosphate + ammonium sulfate	Germination		91.7	95.8	95.8	87.5	58.3	20.8
	Weight		10.3	6.1	2.5	1.0	0.4	0.0
Ammonium phosphate + sodium nitrate	Germination		91.7	100.0	87.5	6.66	29.1	0.0
	Weight		9.0	8.2	2.8	0.5	0.1	0.0
Ammonium sulfate + acid phosphate	Germination		91.7	91.7	95.8	83.3	33.3	58.3
	Weight		7.3	4.1	2.4	0.6	0.3	0.4

Effect of various nitrogen fertilizers alone and in combination on germination and plant growth in a limed and an unlimed loam soil

Since the experiment reported in table 21 had indicated that perhaps the injurious effects of fertilizers at high concentrations when applied alone may

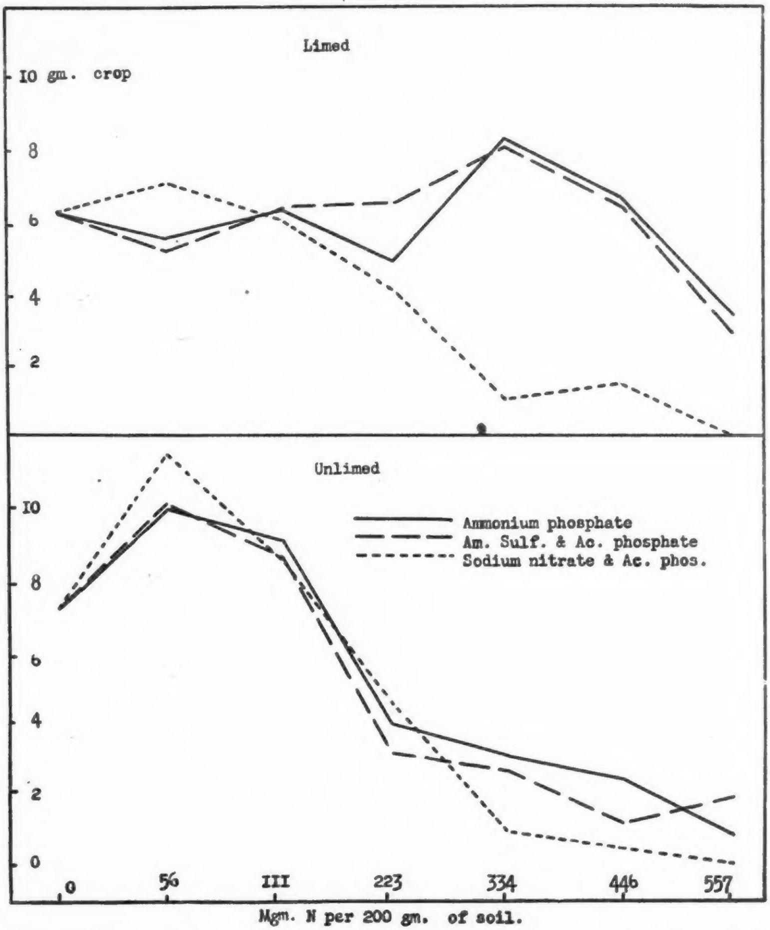

FIG. 9. DIAGRAM SHOWING THE EFFECT OF EXCESSIVE QUANTITIES OF NITROGENOUS FERTILIZERS ON THE EARLY GROWTH OF CORN

be greater than when used in combinations, the experiment reported below was planned. Half of the tumblers received 3 gm. of ground limestone each, while the remainder were left unlimed. Ten seeds were planted in each tumbler after mixing the fertilizer with the 200 gm. of soil. The yield of the corn

crop as well as the percentage of germination is given in table 22, and shown diagrammatically in figures 9 and 10.

From the data presented in table 22 it may be stated that on limed soil ammonium phosphate and the equivalent mixture of acid phosphate and

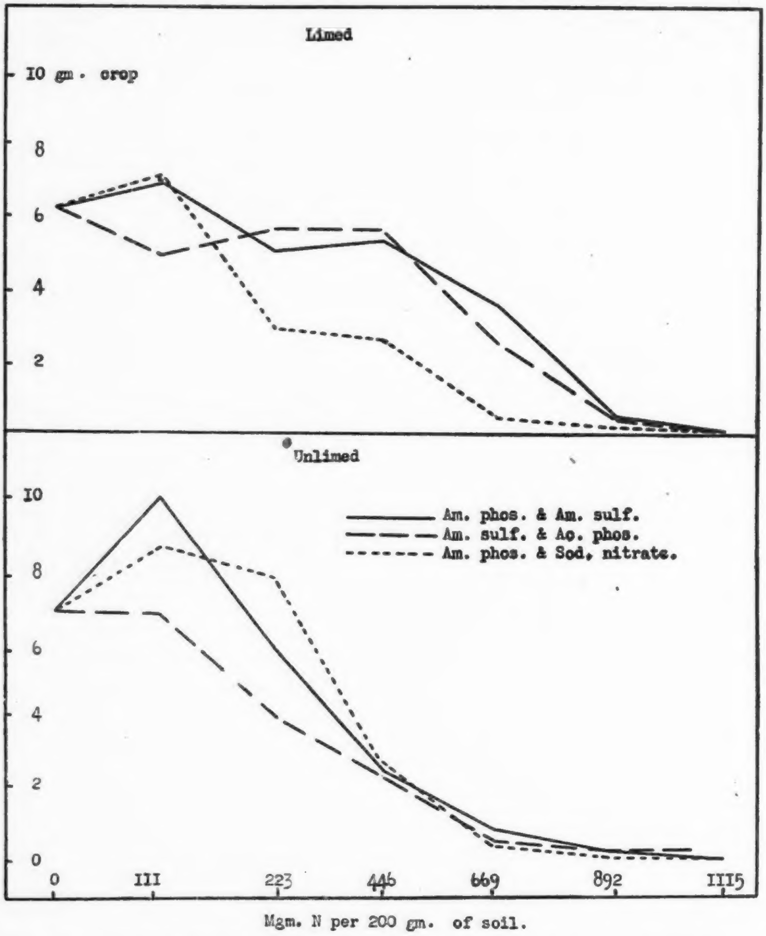

FIG. 10. DIAGRAM SHOWING THE EFFECT OF VARIOUS COMBINATIONS OF NITROGENOUS FERTILIZERS ON THE EARLY GROWTH OF CORN

ammonium sulfate produced equal effects. There was no great difference in the results where ammonium sulfate was used alone or in combination with acid phosphate. On unlimed soil ammonium phosphate was slightly less toxic than the equivalent mixture of ammonium sulfate and acid phosphate.

On both limed and unlimed soil ammonium phosphate in combination with ammonium sulfate was less toxic than the same amount of nitrogen and phosphorus in the form of ammonium sulfate and acid phosphate. On limed soil sodium nitrate was more toxic than either ammonium phosphate or

TABLE 23

Relation of type of soil to the injurious effects of fertilizers on the germination of corn

TREATMENT		0 MGM. NITROGEN	28 MGM. NITROGEN	56 MGM. NITROGEN	112 MGM. NITROGEN	223 MGM. NITROGEN	335 MGM. NITROGEN	446 MGM. NITROGEN	558 MGM. NITROGEN
				Clay					
Check	Germination (per cent)	95.8							
	Weight (gram)	6.6							
Ammonium phosphate.....	Germination		100.0	95.8	91.7	100.0	87.5	100.0	87.5
	Weight		6.9	6.9	7.0	4.2	2.8	3.2	2.3
Ammonium sulfate........	Germination		95.8	91.7	95.8	83.3	95.8	91.7	87.5
	Weight		6.1	6.2	4.8	2.4	2.3	1.7	1.0
				Silt loam					
Check...........	Germination	95.8							
	Weight	7.0							
Ammonium phosphate	Germination		87.5	100.0	95.8	95.8	91.7	91.7	79.2
	Weight		8.3	7.2	6.7	6.7	5.5	2.9	1.9
Ammonium sulfate........	Germination		95.8	91.7	95.8	91.7	100.0	91.7	87.5
	Weight		7.8	7.7	7.4	5.1	4.5	3.5	3.0
				Sandy loam					
Check...........	Germination	95.8							
	Weight	7.2							
Ammonium phosphate.....	Germination		83.3	87.5	100.0	87.5	87.5	95.8	87.5
	Weight		4.8	4.2	3.0	0.9	0.5	0.0	0.0
Ammonium sulfate........	Germination		95.8	95.8	100.0	91.7	91.7	29.1	54.2
	Weight		5.5	4.6	2.9	1.0	0.6	0.0	0.0
				Sand					
Check...........	Germination	100.0							
	Weight	6.2							
Ammonium phosphate......	Germination		91.7	95.8	91.7	33.3	12.4	4.2	0.0
	Weight		4.8	1.0	0.5	0.0	0.0	0.0	0.0
Ammonium sulfate........	Germination		100.0	95.8	83.3	66.6	25.0	20.8	8.3
	Weight.		5.5	1.6	1.0	0.0	0.0	0.0	0.0

ammonium sulfate with acid phosphate. On unlimed soil sodium nitrate with acid phosphate was more toxic than ammonium phosphate, but ammonium phosphate plus sodium nitrate had practically the same effect as ammonium phosphate plus ammonium sulfate.

Relation of type of soil to the germination of corn in the presence of excessive quantities of fertilizers

The germination work reported in the preceding pages had shown, in a rough way, that the heavier the soil the larger is the amount of fertilizer required to affect germination. In order to have a direct comparison between soils, four types were chosen, namely, clay, silt loam, sandy loam and sand. This experiment was carried out in the same manner as those previously discussed, using 200 gm. of air-dried soil and planting 12 kernels of corn per tumbler. The counts were made on the ninth day and the crop harvested and weighed green on the sixteenth day. The results are given in table 23.

The results show very strikingly that very much larger applications of either ammonium phosphate or ammonium sulfate are required for the heavier soils than for the lighter ones to produce a marked injury. Applications which entirely prevented the growth of corn in the sandy soil produced only a slight injury in the clay and silt loam soils. It should be stated that the results obtained for the clay in comparison with the silt loam may be somewhat misleading. Clay, being the heavier soil, would be expected to require more fertilizer to produce an injury and this would probably be true for most clay soils, but the soil used in this experiment was very granular and perhaps we might say cloddy, so that even after sieving through a coarse sieve the soil was quite loose and behaved as a coarser soil. On the other hand, the silt loam was very fine and exceedingly compact when moistened.

In general, it will be noticed that the injury produced by a given amount of nitrogen as ammonium phosphate was about equal to that produced by a like amount of nitrogen as ammonium sulfate except in the clay soil where ammonium phosphate was less toxic than ammonium sulfate. In this experiment no acid phosphate equal to the amount of phosphoric acid in ammonium phosphate was applied to the ammonium sulfate tumblers.

Effect of ammonium phosphate and ammonium sulfate on the germination of corn in quartz sand and in a sandy soil

This experiment, carried out in the same manner as those previously discusssed, was planned to determine the maximum amount of fertilizers that may be applied to a pure sand and a very sandy soil without injury. The quartz sand, of course, need not be considered from the standpoint of field conditions, but the sandy soil was no lighter or poorer than might be used to grow crops in extreme cases. Such a soil would certainly be an exception, though, and represents the extreme that would ever be put under cultivation.

The amounts of ammonium sulfate and acid phosphate used were always equivalent to the amount of nitrogen and phosphoric acid present in the corresponding ammonium phosphate tumblers. Ten kernels of corn were planted in each tumbler, the germination counts being made on the tenth

day and the crop harvested at the end of 25 days. These figures are given in table 24.

It will be noticed that in the case of quartz sand there is an appreciable decrease in germination with 200 mgm. of ammonium phosphate or the corresponding amount of ammonium sulfate, and on the basis of the amount of nitrogen present there is little difference in the toxicity of the two fertilizers. In growth up until the end of the 25-day period it is clearly brought out that even the smallest application used, 50 mgm. per tumbler, produced some injury while 100 mgm. decreased the yield about one-half.

Considering the results with the sandy soil it will be noticed that the decrease in germination began at 750 mgm. of ammonium phosphate per tumbler

TABLE 24

Effect of fertilizers on the germination of corn in quartz sand and in sandy soil

TREATMENT		0 MGM. NITROGEN	5.6 MGM. NITROGEN	11.1 MGM. NITROGEN	22.3 MGM. NITROGEN	33.4 MGM. NITROGEN	44.6 MGM. NITROGEN	55.7 MGM. NITROGEN	83.5 MGM. NITROGEN	111.5 MGM. NITROGEN	167.2 MGM. NITROGEN	223.0 MGM. NITROGEN	278.7 MGM. NITROGEN
Quartz sand													
Check	Germination (per cent)	80.8											
	Weight (gram)	1.1											
Ammonium phosphate	Germination		83.3	83.3	58.3	29.1	29.1	4.2	4.2	0.0	0.0		
	Weight		0.8	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0		
Ammonium sulfate	Germination		79.2	75.0	66.6	16.6	16.6	4.2	0.0	0.0	0.0		
	Weight		0.8	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0		
Sandy soil													
Check	Germination	83.3											
	Weight	1.9											
Ammonium phosphate	Germination		79.2	83.3	83.3		83.3		54.2	33.3	4.2	0.0	0.0
	Weight		2.0	2.3	2.3		0.6		0.1	0.0	0.0	0.0	0.0
Ammonium sulfate	Germination		75.0	83.3	83.3		79.2		45.8	16.6	4.2	4.2	0.0
	Weight		2.0	2.6	lost		0.5		0.1	0.0	0.0	0.0	0.0

or the corresponding amount of ammonium sulfate. Again the two fertilizers showed similar effects on germination. The decrease in growth began at about 200 or 300 mgm. of ammonium phosphate per tumbler.

Comparison of methods of application

This experiment was carried out with the purpose of determining if the injury to germination is lessened by placing the fertilizer at a short distance from the germinating seeds. A Norfolk sand was used. The data are given in table 25, the germination counts being made at the end of 13 days and the plants harvested on the twenty-first day.

The position of the fertilizer in relation to the seed again had very little

effect except possibly in the tumblers where the seeds were planted one inch deep and the fertilizer placed an inch below the seeds. More fertilizer was required in these tumblers to produce a given effect than in any of the other tumblers.

Effect of various nitrogenous salts on the germination of corn

The previous experiments had fixed rather definitely the relation of type of soil to fertilizer injury and also the relative injury that may be expected from the use of ammonium phosphate in comparison with ammonium sulfate or acid phosphate. However, since the data reported in this paper are primarily a study of an impure ammonium phosphate it is of interest to make a further comparison to determine if this commercial phosphate salt will behave in a similar manner to the pure salt, or whether the impurities present

TABLE 25

Comparison of method of application

AMMONIUM PHOSPHATE APPLIED	FERTILIZER IN CONTACT WITH SEED 1.5 INCHES DEEP		FERTILIZER 1 INCH DEEP; SEED 2 INCHES		FERTILIZER 2 INCHES DEEP; SEED 1 INCH		FERTILIZER UNIFORMLY DISTRIBUTED; SEED 1.5 INCHES DEEP	
	Average germination	Average weight	Average germination	Average weight	Average germination	Average weight	Average germination	Average weight
grams	*per cent*	*grams*	*per cent*	*grams*	*per cent*	*grams*	*per cent*	*grams*
Check	97.5	5.0						
0.10	100.0	5.5	100.0	5.6	100.0	6.1	100.0	5.9
0.20	100.0	5.3	100.0	4.6	100.0	6.3	100.0	5.1
0.40	100.0	2.8	100.0	3.5	100.0	4.0	85.0	1.6
0.80	90.0	0.9	95.0	0.8	95.0	3.2	90.0	0.8
1.60			25.0	0.1	100.0	1.7	0.0	0.0
2.40			0.0	0.0	95.0	0.6	0.0	0.0
3.20							0.0	0.0

increase or decrease the injury to germination and plant growth. Furthermore, what relation does ammonium phosphate bear to other nitrogenous salts, especially ammonium salts. The soil chosen for testing these points was the Sassafras loam used in previous experiments. Ten kernels of corn were planted per tumbler and the fertilizers placed in direct contact with the seeds. With the exception of ammonium nitrate the applications were based on the amount of nitrogen present. Only the ammonium nitrogen was considered in the case of this salt. The germination counts were made after 24 days and the crop harvested at the same time. The results are given in table 26.

From the standpoint of the crude ammonium phosphate the most interesting point brought out in the table is that with large applications of the fertilizer the toxic effects are usually no greater than with the pure mono-ammonium phosphate, proving that the effects produced are not to any great extent, if

at all, due to the method of making the fertilizer or to any impurities present. The di- and tri-ammonium phosphates were somewhat less toxic on the basis of the amount of nitrogen present than was the mono form. In agreement with previous work the injury produced by a given amount of the ammonium phosphate fertilizer was practically the same as with ammonium sulfate. Ammonium chloride was the most toxic of all the salts used, undoubtedly because of the chloride radical. Ammonium nitrate, on the basis of the amount of ammonia present, showed about the same degree of toxicity as the ammonium phosphate fertilizer, ammonium sulfate or mono-ammonium phosphate, regardless of the fact that twice as much nitrogen was present,

TABLE 26

Effect of nitrogenous salts on the germination of corn

TREATMENT		0 MGM. NITROGEN	11.5 MGM. NITROGEN	23.0 MGM. NITROGEN	46.0 MGM. NITROGEN	80.5 MGM. NITROGEN	115.0 MGM. NITROGEN	172.0 MGM. NITROGEN
Check.......	Germination (per cent)	86.6						
	Weight (grams)	5.1						
"Ammo Phos"..........	Germination		85.0	95.0	90.0	70.0	65.0	25.0
	Weight		5.3	7.0	3.0	2.9	0.8	0.1
$NH_4H_2PO_4$............	Germination		95.0	90.0	90.0	65.0	40.0	40.0
	Weight		4.5	5.0	4.1	2.6	0.7	0.3
$(NH_4)_2HPO_4$...........	Germination		80.0	100.0	100.0	90.0	65.0	25.0
	Weight		4.3	7.2	7.4	3.2	1.8	0.2
$(NH_4)_3PO_4$.............	Germination		100.0	95.0	100.0	95.0	75.0	70.0
	Weight		6.5	5.2	5.8	3.6	2.5	2.4
$(NH_4)_2SO_4$.............	Germination		100.0	95.0	100.0	90.0	90.0	60.0
	Weight		5.8	7.0	5.4	3.2	2.2	0.3
NH_4Cl................	Germination		80.0	80.0	85.0	55.0	40.0	15.0
	Weight		5.0	5.1	1.3	0.6	0.2	0.0
NH_4NO_3..............	Germination		90.0	90.0	85.0	75.0	60.0	10.0
	Weight		6.7	6.7	3.3	2.8	0.9	0.0
$NaNO_3$................	Germination		85.0	90.0	90.0	85.0	80.0	20.0
	Weight		5.8	6.9	5.4	2.2	1.9	0.1

half as ammonia and half as nitrate nitrogen. Sodium nitrate showed a slightly higher degree of toxicity than did the commercial ammonium phosphate fertilizer, but was not as toxic as ammonium chloride.

The results of this experiment indicate that the concentration of the salt, whatever that salt may be, is the primary cause of the injury to germination and young plants. Secondary to this is the acid radical and the base to which it is combined. In the case of ammonium salts, as is brought out in table 26, the presence of the chloride radical resulted in a much greater injury than the nitrate.

Germination of corn in the field in the presence of ammonium phosphate

After completing the germination tests in tumblers reported in the previous pages it seemed desirable to carry on some field work to determine just how much ammonium phosphate fertilizer may be applied to corn in the row without injury. Consequently on May 30, 1917 an experiment was begun on a Sassafras loam, which is the same soil used frequently in the germination experiments in the laboratory. Rows were laid off 1 foot apart and 50 kernels of corn planted per row, about 2 to 3 inches apart. The ammonium phosphate was applied in the row in a strip about 1 inch wide in direct contact with the seed, exactly as if applied with a seed drill having a fertilizer attachment. The rates of application were based on rows 32 inches apart. In other words, each linear foot received the same amount of ammonium phosphate as it would in the field in rows 32 inches apart at the given rates per acre. The germination was counted on June 11 and 21 and is given in table 27.

TABLE 27

Germination of corn in field fertilized with ammonium phosphate

POUNDS OF AMMONIUM PHOSPHATE PER ACRE IN ROW WITH SEED	GERMINATION (NUMBER OF KERNELS SPROUTED)							
	12 days				22 days			
	1	2	3	Average	1	2	3	Average
0	48	50	49	49	48	49	49	49
25	49	49	49	49	48	49	49	49
50	44	48	49	47	43	48	49	47
100	47	50	48	48	46	50	48	48
150	37	44	46	42	41	46	46	44
200	34	41	39	38	37	42	41	40
300	23	29	20	24	26	35	25	29
400	17	22	19	19	21	25	24	23
500	7	11	8	9	11	13	17	14

The corn on the rows with 50 and 100 pounds appeared to be best and was equal in size, color and apparent vigor. The rows with 150 pounds showed the effects of too much fertilizer. The decrease in the size of the plants with increasing applications of fertilizer was about proportional to the numbers given for germination. With 150 pounds and over there were a few plants, about 5 to 10 per cent, which looked yellow and stunted, and will probably die. The balance were dark green and not injured to any extent, if at all. The corn on the rows with 50 and 100 pounds was about 9 inches high and of very good color at the time of making the second germination counts. In this test 100 pounds is a perfectly safe application per acre. This was a very wet season, however, which should be more favorable than a dry season. It should also be borne in mind that the soil used is fairly heavy. Further tests are necessary before general conclusions can be drawn.

General discussion of germination experiments

The results of the germination experiments show that ammonium phosphate when applied to the soil has practically the same effect upon germination as a mixture of acid phosphate and ammonium sulfate in the same proportion as the plant-food constituents present in the ammonium phosphate fertilizer. In fact, such a large amount of acid phosphate was required to injure germination that we may say that the ammonium phosphate produces results quite similar to ammonium sulfate used alone. It has also been brought out that any injury produced by the commercial ammonium phosphate is due to the concentration of the soluble salts and not to any impurities that are present, for the injury produced by chemically pure mono-ammonium phosphate is just as great. Other salts, such as ammonium chloride and sodium nitrate, may produce even greater injury than ammonium phosphate. Evidently, then, the acid radical exerts its influence, but with most salts it is the concentration of the soluble material about the germinating seeds that plays the primary rôle. As was brought out earlier it is very significant that ammonium nitrate, on the basis of the amount of ammonia present, showed no greater toxicity than ammonium phosphate or ammonium sulfate, yet there was twice as much nitrogen present, half as ammonia and the remainder as nitrate nitrogen.

Regarding the migration of soluble fertilizer salts in the soil, these experiments have shown that under the conditions prevailing in the tumblers the salts are carried from one point to another with sufficient rapidity to affect the germinating seed regardless of the method of application, whether at some particular point in the soil or uniformly distributed throughout the 200-gm. sample. However, these results must not be applied too closely to field conditions, where rains usually come at intermittent periods rather than as a small amount every day, as was the case in the tumblers.

Investigators disagree as to the rapidity with which soluble salts diffuse through the soil. Harris (9) shows that salts are transferred through the soil readily by moving water. Malpeaux and Lefort (23) showed that the diffusion of nitrates was comparatively slow and was practically the same laterally as vertically. Sprinkling accelerated downward as well as lateral diffusion but there was rather a rapid return to the upper layers of soil by capillarity. The diffusion was more rapid in the sandy soil but less uniform. He concludes that under ordinary conditions of rainfall there is a comparatively rapid diffusion of the nitrates in the surface soil. Müntz and Gaudeschon (25) conclude that the most soluble substances diffuse in the soil only with extreme slowness. The writer is of the opinion that under ordinary field conditions soluble salts are washed down to the subsoil and again brought to the surface by capillarity very readily, but that the lateral diffusion is almost negligible.

How much fertilizer may be applied safely under field conditions without

injury if in direct contact with the seed? This question has not been completely answered by the experiments reported but some progress has been made. In the first place the crop grown must be considered. Basing our statements on table 20 we may say that corn, buckwheat, oats, wheat and barley are resistant crops, while vetch, rape and cowpeas may be considered as relatively easily injured. Since most of this work deals with the germination of corn we should bear in mind that this crop is relatively resistant and a greater injury would be expected with some other crops, especially those with high oil content, such as cowpeas, soybeans and cotton.

Kearney and Harter (12), using alkali salts and eight species of plants, found that in water culture maize was on the whole the most resistant to pure solutions and cotton the least. Harris (8) working with alkali salts, found that the relative resistance of various crops in the seedling stage is usually in the following order, barley being the most resistant, barley, oats, wheat, alfalfa, sugar beets, corn and Canada field peas. Only about half as much alkali was required to prohibit the growth of crops in sand as in loam. He further states that the period of germination of seeds is considerably lengthened by the presence of soluble salts in the soil. The same observation was made by the writer, using the different fertilizers.

Another point which must be considered is the type of soil. As was brought out in table 23 the amount of fertilizer required to produce a given injury in a clay or silt loam soil is probably ten times as much as is required in a sandy soil, at least under laboratory conditions. The injury would probably not be quite as great under field conditions but nevertheless it is a well known fact that there is a big difference between soils. This may be partially attributed to the variations in the water-holding capacity, but also to the fact that the heavier soils have a greater absorbing capacity. On the other hand, it should be borne in mind that the fertilizer will distribute itself more rapidly in a lighter soil, and when applied in the row this factor would enter in to decrease the injury that we would otherwise expect to occur.

Judging from the one field experiment reported it would seem that it is reasonably safe to apply as much as 100 pounds of ammonium phosphate per acre drilled in the corn row on the average soil, but it must be borne in mind that this experiment was conducted during a wet month. It is to be regretted that lack of time prevented the carrying out of a variety of field experiments. The tumbler experiments, however, have been sufficient practically to prove that a given amount of nitrogen as sodium nitrate or ammonium sulfate will produce just as great an injury as the same amount of nitrogen as ammonium phosphate, but this does not settle the question because there is little experimental evidence to show how much of these salts may be applied with safety in drills. It is usually customary to consider that such a fertilizer as ammonium sulfate in moderate amounts may be drilled in the row with safety, but in the light of the results reported here it seems doubtful. It is a well known fact that the farmer has a prejudice in favor of organic fertilizers even though

the nitrogen is not as available as that in ammonium sulfate. Perhaps this prejudice is after all a just one and it would seem so since it has grown up as a result of many years of experience. Even in so-called moderate amounts the ammoniate fertilizers, when applied in the drill, may produce marked injury, especially in dry seasons on sandy soils. The remedy seems to be either to apply smaller amounts of the soluble fertilizer in the drill, or to spread it over a wider strip in the row, or to make applications alongside the row or broadcast.

CONCLUSIONS

From the results of the work which has been reported in the preceding pages it may be briefly said that the ammonium phosphate fertilizer is in general of the same value as an equivalent amount of nitrogen as ammonium sulfate and phosphorus as acid phosphate, and may be used as a substitute for these other forms of plant-food. While in isolated cases this statement did not hold true, they were so few and under such abnormal soil conditions that they scarcely need be considered. In fact, the number of cases where ammonium phosphate was slightly superior to ammonium sulfate was larger than where the reverse was true. Ammonium phosphate is readily nitrified and utilized by both microorganisms and plants.

From the standpoint of injurious effects when applied in high concentrations, ammonium phosphate is again similar to ammonium sulfate and slightly less toxic than sodium nitrate. In its application in drills caution should be used in regard to the amount applied, but this statement applies to other soluble salts as well.

SUMMARY

The chief points which have been brought out in this thesis may be summarized as follows:

1. The commercial ammonium phosphate fertilizer used contains approximately 13.5 per cent of ammonia and 43 per cent of phosphoric acid, 96.5 per cent of which is either water- or citrate-soluble.

2. Ammonium sulfate and ammonium phosphate nitrify at approximately the same rate, while dried blood, cottonseed meal and tankage are considerably less available, usually in the order named, tankage being the least available.

3. A gradual increase in nitrate accumulation was found in tumblers up until the sixth week in a rich garden soil and until 8 to 10 weeks in a meadow soil. After the maximum accumulation in the garden soil the decline was quite rapid, showing the importance that may be attached to nitrate assimilation by microörganisms.

4. Calcium carbonate proved to be especially favorable for nitrification while calcium oxide sometimes caused an actual depression in the nitrification of ammonium sulfate and ammonium phosphate.

5. Ammonium phosphate increased the rate of ammonification of cotton-

seed meal but decreased the ammonia production from dried blood. Green alfalfa was not appreciably affected by the presence of the fertilizer.

6. Soil fungi were found to utilize nitrogenous salts in solution in the following order, sodium nitrate showing the poorest results, ammonium phosphate ammonium carbonate, ammonium sulfate, urea, ammonium nitrate and sodium nitrate.

7. As an average of all conditions the recoveries of nitrogen applied to Norfolk sand, yielding six crops—one of barley, four of buckwheat and one of corn, were 65.88, 61.10, 43.74 and 41.19, respectively, for ammonium phosphate, ammonium sulfate, dried blood and cottonseed meal. On a Sassafras loam the average recoveries in the same order were, 48.46, 50.42, 42.51 and 36.49. Liming usually increased the recovery of nitrogen. The crop yields were about in the same ratio as the nitrogen recoveries, except that under very acid conditions frequently ammonium sulfate showed a higher recovery of nitrogen than ammonium phosphate but a much smaller crop. The comparatively low recovery of the nitrogen added leads the writer to believe that a considerable amount of nitrogen escapes from soil as free nitrogen gas or ammonia or is given off from the plant itself.

8. The average of the results for two soils, limed and unlimed, with two rates of application of fertilizers, showed the following increases in lime requirement over checks, due to the fertilizers applied: ammonium sulfate, 794 pounds of CaO; ammonium phosphate, 525 pounds; dried blood, 263 pounds; and cottonseed meal, 113 pounds.

9. Pot experiments in sand showed the nitrogen in the commercial ammonium phosphate, the water-soluble extract of ammonium phosphate and sodium nitrate to be of practically the same availability. Water-insoluble ammonium phosphate showed only a slightly lower yield than the other forms of nitrogen.

10. Experiments in soils in the greenhouse, as an average, showed little difference in the availability of the phosphorus between ammonium phosphate, acid phosphate and basic slag, while raw rock phosphate gave much smaller increases. On very acid soils acid phosphate was sometimes superior to ammonium phosphate as a source of phosphorus, doubtless because the former does not increase the acidity to any great extent, if at all, while ammonium phosphate does increase the acidity somewhat. In quartz sand the relative increases over the check were for ammonium phosphate 9.95 gm., acid phosphate 9.50 gm. and raw rock phosphate 3.10 gm.

11. In germination experiments ammonium phosphate, on the basis of the amount of nitrogen present, showed about the same toxicity to germination and early growth as ammonium sulfate and less than sodium nitrate or ammonium chloride when applied to soils in high concentrations.

12. Very sandy soils require only about one-tenth as much fertilizer in tumblers to produce a given injury as heavy clay or silt soils.

13. The commercial ammonium phosphate was no more toxic than the pure mono-ammonium phosphate.

14. Liming decreased the growth of the young corn plants at the lower rates of application of the fertilizers in the germination experiments, but favored the plants at the higher rates. Using various combinations of fertilizers did not lessen the injury of individual salts to any extent, if at all.

15. Corn, buckwheat, barley, wheat and oats were resistant to large applications of fertilizers, while vetch, rape and cowpeas were relatively susceptible.

16. Under laboratory conditions, using tumblers holding 200 gm. of soil, the injury produced by a given amount of the fertilizers was practically the same whether applied in direct contact with the seed or uniformly mixed with the soil.

17. Under field conditions applications of 100 pounds of ammonium phosphate per acre in the row did not injure the germination of corn, while the 150-pound applications showed a slight injury.

ACKNOWLEDGEMENTS

The writer wishes to express his thanks to Dr. J. G. Lipman, Prof. A. W. Blair, Mr. E. J. Pranke and various fellow-workers in the laboratory for their help and suggestions during the progress of the work.

REFERENCES

(1) Beseler, O., and Maercker, M. 1883 Versuche über den Einfluss der Aussaatstärke und der anwendung künstlicher Düngemittel auf den Ertrag und die Zusammensetzung des Hafers. *In* Centbl. Agr. Chem., Bd. 12, p. 472–480; Bd. 13 (1884), p. 453–461.

(2) Boussingault 1858 Sur l'action de salpetre employe comme engrais. *In* Jour. Agr. Prat., t. 2, p. 446–449.

(3) Claudel, and Cochetelle, J. 1896 Effect of some substances used as manures on germination. *In* Ann. Agron., t. 22, p. 131–142.

(4) Cook, R. C., and Allison, F. E. 1917 Effect of soil reaction upon the availability of ammonium sulfate. *In* Soil Sci., v. 3, p. 487–498.

(5) Ehrenberg, P. 1907 The movement of ammoniacal nitrogen in nature. *In* Mitt. Landw. Inst. Breslau, Bd. 4, Heft 1–2, p. 47–300.

(6) Hall, A. D., and Gimingham, C. T. 1907 The interaction of ammonium salts and the constituents of the soil. *In* Jour. Chem. Soc. [London], v. 91–92, no. 534, p. 677–687.

(7) Hals, S. 1902 Ammoniacal and nitric nitrogen. *In* Tidsskr. Norske Landbr., v. 9, no. 5, p. 212–225.

(8) Harris, F. S. 1915 Effect of alkali salts in soils on the germination and growth of crops. *In* Jour. Agr. Research, v. 5, no. 1, p. 1–53.

(9) Harris, F. S. 1915 The movement of soluble salts with the soil moisture. *In* Utah Agr. Exp. Sta. Bul. 139, p. 119–124.

(10) Immendorff, H. 1892 Beiträge zur Lösung der "Stickstoffrage." *In* Landw. Jahrb., Bd. 31, p. 281–339.

(11) Johnson, S. W. 1883 How Crops Feed, p. 301–304. Orange Judd Co., New York.

(12) Kearney, T. H., and Harter, L. L. 1907 Comparative tolerance of various plants for the salts common in alkali soils. U. S. Dept. Agr. Bur. Plant Indus. Bul. 113, p. 22.

(13) Kretschiner, et al. 1906 Field experiments on the fertilizing action of sulphate of ammonia and nitrate of soda. *In* Arb. Deut. Landw. Gesell., No. 121, 234 + xxiii p.

(14) Lemmermann, O., et al. 1911 Investigations on the behavior of ammoniacal nitrogen in limed and unlimed soil. *In* Landw. Jahrb., Bd. 40, p. 173–244, 255–324.
(15) Lemmermann O., et al. 1912 Increasing of ammonia-fixing power of soils under the influence of calcium carbonate. *In* Fuhling's Landw. Ztg., Bd. 61, No. 7, p. 240–253.
(16) Lint, H. C., and Coleman, D. A. 1916 Sources of error in bacteriological analysis of soils. *In* Soil Sci., v. 2, no. 2, p. 157–163.
(17) Lipman, C. B., and Gericke, W. F. 1916 A vegetation experiment on the nitrogenous fertilizers in an arid soil. *In* Soil Sci., v. 2, p. 575–581.
(18) Lipman, J. G., and Brown, P. E. 1907 Ammonification in culture solutions as affected by soil treatment. *In* N. J. Agr. Exp. Sta. 28th Ann. Rpt. (1907), p. 195–199.
(19) Lipman, J. G., Brown, P. E., and Owen, I. L. 1909 Comparative tests on the ammonification and nitrification of nitrogenous materials. *In* N. J. Agr. Exp. Sta. 30th Ann. Rpt. (1909), p. 169–174.
(20) Lipman, J. G., Brown, P. E., and Owen, I. L. 1910 The relative availability of nitrogenous materials as measured by nitrification. *In* N. J. Agr. Exp. Sta. 31st Ann. Rpt. (1910), p. 151–155.
(21) Lipman, J. G., Blair, A. W., Owen, I. L., and McLean, H. C. 1912 Report of the soil chemist and bacteriologist. *In* N. J. Agr Exp. Sta. 33rd Ann. Rpt. (1912), p. 209.
(22) Lipman, J. G., and Blair, A. W. 1916 Investigations relative to the use of nitrogenous plant-foods, 1898–1912. N. J. Agr. Exp. Sta. Bul. 288, 124 p.
(23) Malpeaux, L., and Lefort, G. 1912 The circulation of nitrates in the soil. *In* Ann. Sci. Agron., s. 4, ann. 1, t. 2, p. 241–258.
(24) Mayer, A. 1901 Ueber die Bedingungen des Entstehens der Eiweissstoffe in der Pflanze. *In* Landw. Vers. Stat., Bd. 55, p. 453–461.
(25) Müntz, A., and Gaudechon, H. 1908 The diffusion of fertilizer salts in the soil. *In* Ann. Inst. Nat. Agron., s. 2, t. 7, no. 2, p. 205–238.
(26) Müntz, A., and Nottin, P. 1907 Studies on the value of calcium cyanamid as a nitrogenous fertilizer. *In* Ann. Inst. Nat. Agron., s. 2, t. 6, no. 1, p. 145–183.
(27) Pantanelli, E., and Severini, G. 1910 Some experiments on the utilization of ammonium salts by green plants. *In* Staz. Sper. Agr. Ital., v. 43, no. 6, p. 449–544.
(28) Ritthausen, H., and Pott, R. 1873 Untersuchungen über den Einflus einer an Stickstoff und Phosphorsäure de Pflanze und der Samen von Sommerweizen. *In* Landw. Vers. Stat. Bd. 16, p. 384.
(29) Rusche, A. 1912 Influence of various fertilizers on the germination of field crop seeds. *In* Jour. Landw., Bd. 60, No. 4, p. 305–365.
(30) Schäfer-Heide, A. 1906 Die Ausnutzung des Ammoniakstickstoff. *In* Compt. Rend. Acad Sci. [Paris], t. 140, p. 1190.
(31) Schreiber, C. 1908 Recent investigations of the nitrogenous fertilizers. *In* Rev. Gén. Agron., n. s., t. 3, no. 11, 433–440; no. 12, p. 481–486; t. 4, no. 1, p. 4–9.
(32) Steffeck, H., and Maercker, M. 1896 Efficacy of various manures. *In* Jahrb. Agr. Chem. Vers. Stat. Halle, 1896, p. 105–131.
(33) Tanret, Chas. 1897 Action of ammonium salts on *Aspergillus niger*. *In* Bul. Soc. Chim. Paris, s. 3 t. 17, p. 914–921.
(34) Wagner, P. 1892 Die Stickstoffdüngung der Landwirtschaftlichen Kulturpflanzen, Berlin, 1892. *Abs. in* Centbl. Agr. Chem., Bd. 21, p. 791–792.
(35) Wagner, P., Hamann, G., and Münzinger, A. 1907 Experiences aver le nitrate de soundre, les sels diamamonium et la chaux azote comme engrais. *In* Arb. Deut. Landw. Gesell., 1907, No. 129, p. vi + 286.
(36) Wilfarth, H., Römer H., and Wimmer, G. 1906 Über die Nahrstoffaufnahme der Pflanzen in verschiedenen Zeiten ihres Wachstums. *In* Landw. Vers. Stat., Bd. 63, p 1-70.

THE SIGNIFICANCE OF THE SULFUR IN SULFATE OF AMMONIA APPLIED TO CERTAIN SOILS

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Received for publication October 6, 1917

The superiority of sulfate of ammonia to nitrate of soda, nitrate of lime, and other nitrogenous fertilizers for the production of barley, in certain soil types in California, which we have demonstrated (1) led us to inquire into the more direct nature of its cause. While we had shown the high coefficient of nitrifiability which characterizes sulfate of ammonia in those soils to be the cause of its superiority over other nitrifiable materials, it did not appear entirely clear why nitrate of soda and particularly nitrate of calcium should not be equally good with moisture conditions being maintained at the optimum. After studying the situation, it occurred to us that the sulfur of the ammonium sulfate might be the cause of its superiority over the nitrate fertilizers. This seemed particularly reasonable since the soils under study are markedly deficient in organic matter and hence do not support a vigorous sulfofying flora. We, therefore, inaugurated an experiment to determine the rôle of sulfur, in barley growth on one type of the soils in question, when used in conjunction with nitrogenous fertilizers. It was argued that if sulfur in one or more forms, when combined with nitrates, induced similar yields to those obtained with sulfate of ammonia, the sulfur must be the cause of the superiority of the ammonium salt over the nitrates in the cases in question.

DESCRIPTION OF THE EXPERIMENT

The soil employed was the Oakley blow sand, which we have already described in detail elsewhere (2). It was placed in glazed earthenware jars such as those commonly used in greenhouse work. Every test was made in triplicate jars, except in some cases in which the lack of sufficient soil rendered it necessary to employ only duplicate jars. Two parallel series were run. In the first, the various nitrogenous fertilizers were used as in the experiments above cited. In the second, the same nitrogenous fertilizers were used in the same way, but sulfur in various forms was added to each. The amount of nitrogen employed was equivalent in all cases to that added on the basis of a field application of dried blood at the rate of 1000 pounds per acre. Similarly, sulfur was used in the same quantity for all cultures to which it was applied, regardless of the form used and was equivalent to the amount of sulfur contained in the sulfate of ammonia application alone. Nitrogen was

employed in the forms of sulfate of ammonia, nitrate of soda, nitrate of lime, and dried blood. Sulfur was used in the forms of flowers of sulfur, sulfuric acid, and sodium sulfate. The applications of the various materials were made in accordance with the usual procedure which is based on the properties of every one of the substances. The moisture content of the soil was maintained uniformly in all the jars and at as near the optimum point as possible. Twelve barley seeds of the Beldi variety, from selected heads, were planted in every jar as in all other experiments, and the plants were thinned to six after they had attained a height of 3 to 4 inches. At the end of the growing season, determinations were made of the number of heads of grain per jar, the number of tillers, the total height of tillers, and the dry weights of straw, of grain, and of roots. Control jars were used, for growing plants, in which no fertilizer and no sulfur were employed and others in which only sulfur, but no nitrogen was applied. The data gathered are presented in the accompanying tables. It is at once apparent even from a brief study of the data given, that, in the first place, sulfate of ammonia is far superior to the other nitrogenous fertilizers for barley growth under the conditions described above. Secondly, it is clear that sulfur in all forms, when supplementing the nitrate or blood, induces marked increases in barley growth over and above that induced by the nitrogen alone. Thirdly, the sulfur without the nitrogen is practically without effect on barley production on the Oakley blow sand.

Considering the figures more in detail, it is obvious in the first table that marked effects, for the better, result from the application of nitrogen as regards the height of the stalks produced. The number of stalks or of heads produced, however, is only slightly affected, if at all, by all forms of nitrogen except sulfate of ammonia, which stimulates their production very markedly. When however, sulfur is added to the nitrogen, very striking increases in the number of heads and stalks occur in the case of all the jars, without any marked increase in the total height of the stalks. Moreover, the increases noted are, in most cases, sufficient to render the total growth about equivalent in those jars to that obtained in the sulfate of ammonia jars. This is true when any form of sulfur is added to nitrate of soda, but flowers of sulfur are not as good in that direction as sulfuric acid or sodium sulfate. On the other hand, it is true for nitrate of lime only in the cases of flowers of sulfur and sodium sulfate, but not in that of sulfuric acid, which actually depresses growth below that obtained when only nitrate of lime is applied. In the case of dried blood, sodium sulfate was not used and of the other two forms of sulfur, one—sulfuric acid—stimulated the plants in the directions indicated markedly, while the other—flowers of sulfur—was almost without effect.

Coming now to the more accurately measurable criteria for judging of the effects of nitrogen and sulfur on the barley plants, viz., the weights of straw, grain, and roots, the following observations are easily made. The application of sulfate of ammonia to the Oakley sand resulted in the production of about fourteen times as much total dry matter as that produced in the untreated

control jars. The jars treated with nitrate of soda, nitrate of lime, or dried blood, produced only a little more than half as much dry matter as those treated with sulfate of ammonia, the blood being slightly superior to the other two. When any form of sulfur is added to the Oakley sand without nitrogen,

TABLE 1

Number and height of shoots and number of heads

NUMBER	NITROGENOUS FERTILIZER	FORM OF SULFUR	NUMBER OF PLANTS PER POT	NUMBER OF HEADS PER POT	NUMBER OF SHOOTS PER POT	TOTAL HEIGHT OF SHOOTS	AVERAGE HEIGHT OF SHOOTS
						inches	*inches*
1	$(NH_4)_2SO_4$		6	14	15	475.5	31.7
2	$(NH_4)_2SO_4$		6	12	12	384.5	32.0
3	$(NH_4)_2SO_4$		6	12	12	404.0	33.7
4	$NaNO_3$		6	6	6	218.5	36.4
5	$NaNO_3$		6	8	8	253.0	31.6
6	$NaNO_3$		6	6	6	215.5	35.9
7	$Ca(NO_3)_2$		6	6	6	207.0	34,5
8	$Ca(NO_3)_2$		6	7	8	246.0	30.8
9							
10	Blood		6	8	9	254.5	28.3
11	Blood		6	7	8	247.0	30.9
12		Na_2SO_4	6	6	6	106.0	17.7
13		Na_2SO_4	6	6	6	92.0	15.3
14		H_2SO_4	6	6	6	104.0	17.3
15		H_2SO_4	6	6	6	100.0	16.6
16		Sulfur	6	6	6	99.0	16.5
17		Sulfur	6	6	6	124.0	20.7
18	$NaNO_3$	Na_2SO_4	6	12	13	414.0	31.8
19	$NaNO_3$	Na_2SO_4	6	10	10	312.5	31.2
20	$NaNO_3$	H_2SO_4	6	12	12	403.0	33.6
21	$NaNO_3$	H_2SO_4	6	10	13	434.5	33.4
22	$NaNO_3$	Sulfur	6	10	11	315.0	28.6
23	$NaNO_3$	Sulfur	6	9	9	305.0	33.9
24	$Ca(NO_3)_2$	Na_2SO_4	6	14	15	412.0	27.5
25	$Ca(NO_3)_2$	Na_2SO_4	6	10	10	323.0	32.3
26	$Ca(NO_3)_2$	H_2SO_4	6	6	6	182.0	30.3
27	$Ca(NO_3)_2$	H_2SO_4	6	6	6	203.0	37.1
28	$Ca(NO_3)_2$	Sulfur	6	12	12	388.5	32.3
29	$Ca(NO_3)_2$	Sulfur					
30	Blood	H_2SO_4	6	11	11	327.0	29.7
31	Blood	H_2SO_4	6	12	12	382.0	31.8
32	Blood	Sulfur	6	9	9	276.0	30.7
33	Blood	Sulfur	6	7	9	286.0	31.8
34	Control		6	6	6	95.0	15.9
35	Control		6	6	6	110.0	18.3

it is without effect as regards the dry matter produced, just as it was described above to be, in so far as the numbers of heads and stalks are concerned. When, however, sulfur in any form is added, as described above, to the nitrates or to dried blood, it induces marked increases in the production of dry matter over

that produced by the nitrogen alone and, in most cases, the quantity of such increase is great enough to bring the total yield up to that of the sulfate of ammonia jars or nearly so. As was true in the case of the number of heads and stalks produced, flowers of sulfur appears to be less efficient than the other

TABLE 2

Yields of straw, grain and roots obtained in experiment

NUMBER	NITROGENOUS FERTILIZER	FORM OF SULFUR	WEIGHT OF STRAW	AVERAGE WEIGHT OF STRAW	WEIGHT OF GRAIN	AVERAGE WEIGHT OF GRAIN	WEIGHT OF ROOTS	AVERAGE WEIGHT OF ROOTS	TOTAL DRY WEIGHT	AVERAGE TOTAL DRY WEIGHT
			grams	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*	*grams*
1	$(NH_4)_2SO_4$		23.94	23.38	16.06	15.69	5.27	6.84	45.27	45.90
2	$(NH_4)_2SO_4$		23.17		14.83		7.20		45.20	
3	$(NH_4)_2SO_4$		23.02		16.18		8.04		47.24	
4	$NaNO_3$		11.65	11.99	8.15	8.95	5.60	4.91	25.40	25.85
5	$NaNO_3$		14.05		10.95		4.95		29.95	
6	$NaNO_3$		10.26		7.74		4.20		22.20	
7	$Ca(NO_3)_2$		11.18	13.09	6.82	8.91	5.40	6.60	23.40	28.60
8	$Ca(NO_3)_2$		15.00		11.00		7.80		33.80	
9	Lost									
10	Blood		14.46	13.97	11.03	11.28	5.06	5.08	30.55	30.33
11	Blood		13.47		11.53		5.10		30.10	
12		Na_2SO_4	1.24	1.35	1.46	1.40	0.40	0.40	3.10	3.15
13		Na_2SO_4	1.46		1.34		0.40	0.40	3.20	
14		H_2SO_4	0.94	1.52	1.46	1.18	0.22	0.37	2.62	3.07
15		H_2SO_4	2.10		0.90		0.52		3.52	
16		Sulfur	1.54	1.97	1.46	2.53	0.60	1.25	3.60	5.75
17		Sulfur	2.40		3.60		1.90		7.90	
18	$NaNO_3$	Na_2SO_4	20.94	20.66	15.06	14.84	8.26	8.73	44.26	44.23
19	$NaNO_3$	Na_2SO_4	20.38		14.62		9.20		44.20	
20	$NaNO_3$	H_2SO_4	22.00	23.90	16.00	16.40	7.70	6.60	45.70	46.90
21	$NaNO_3$	H_2SO_4	25.80		16.79		5.50		48.09	
22	$NaNO_3$	Sulfur	18.17	17.32	12.43	12.30	5.00	6.30	35.60	35.92
23	$NaNO_3$	Sulfur	16.47		12.17		7.60		36.24	
24	$Ca(NO_3)_2$	Na_2SO_4	23.35	26.61	16.65	15.39	9.50	7.75	49.50	44.75
25	$Ca(NO_3)_2$	Na_2SO_4	29.87		14.13		6.00		40.00	
26	$Ca(NO_3)_2$	H_2SO_4	7.50	9.56	5.60	6.69	2.15	3.38	15.25	19.63
27	$Ca(NO_3)_2$	H_2SO_4	11.62		7.78		4.60		24.00	
28	$Ca(NO_3)_2$	Sulfur	18.80	18.80	14.20	14.20	1.08	10.80	43.80	43.80
29	$CaNO_3$	Sulfur	Contaminated by rain							
30	Blood	H_2SO_4	17.55	18.08	13.64	14.22	11.00	9.40	42.19	41.70
31	Blood	H_2SO_4	18.60		14.80		7.80		41.20	
32	Blood	Sulfur	17.62	17.26	13.08	12.09	7.80	9.40	38.50	38.75
33	Blood	Sulfur	16.90		11.10		11.00		39.00	
34	Control		1.54	1.64	1.26	1.26	0.40	0.45	3.20	3.75
35	Control		1.74		1.26		0.50		3.50	

forms in increasing dry-matter production over that of the nitrogen-treated pots alone, but is none the less markedly stimulating in that respect. It seems, moreover, to be slightly more efficient when added to dried blood than when

added to nitrate of soda but the difference is not great. On the other hand, sulfuric acid is more efficient when supplementing nitrate of soda than when supplementing dried blood. As regards total dry-matter production, sulfuric acid acts similarly when added to calcium nitrate as it does with regard to the production of heads and stalks.

Sodium sulfate is equally stimulating when used with nitrate of soda or with nitrate of lime, and sulfuric acid is likewise so for nitrate of soda and for dried blood. Flowers of sulfur show similarity to the other forms of sulfur in maximum stimulation with regard to one case only, viz., when it is added to nitrate of lime. Unfortunately, one of the duplicate jars in this case was lost and the figure obtained is, therefore, not as reliable as it would otherwise have been.

In general, our data seem to show beyond question that, barring certain pronounced side-effects, such as that evidently obtaining in the nitrate of lime-sulfuric acid cultures, equally good results in barley production can be obtained on soils of the type in question with the nitrates and with blood as with sulfate of ammonia, if sulfur is added in proper form and quantity. Just why sulfuric acid, when added to nitrate of lime, should produce an effect so strikingly different from that produced by it when added to nitrate of soda seems at first sight not very clear. A little reflection brings forward the thought, however, that the greater solubility of the sodium sulfate than that of the calcium sulfate, the salts resulting in the two cases, may account for the supply of sufficient available sulfur in one case and not in the other; and hence the difference in effects on the barley plant. This explanation is not entirely satisfying, however, owing to the very marked depression in the growth of the barley plants induced by sulfuric acid when it is added to calcium nitrate. Another factor entering into the problem may be the loss of nitric acid which may be greater in one case than the other when the acid is added to the nitrate.

The fact above noted of the non-effectiveness of all the forms of sulfur when applied to the soil without nitrogen, requires perhaps another word of comment. If, as seems true from our data, sulfur is needed by the barley plant on the soil in question, why should not sulfur exert at least a part of its beneficial effect even when nitrogen is not added with it? The answer may be in the theoretical consideration, which we propose, to the effect that nitrogen, being needed in this case far more than sulfur, the latter is powerless to influence the plant in the building of further protein substances, to the building of which that nitrogen is absolutely essential.

In view of the striking nature of the results above described, the method of improving the Oakley blow sand and similar soils covering large areas in this state is clearly indicated. Nitrogen in some readily available form must be used as fertilizer until such time as it shall be possible to increase the nitrogen and organic matter content of the soil by means like green manuring, and the efficient use of nitrogen-fixing bacteria. The choice of the most profitable form of nitrogen can be determined by reference to the tables

submitted herewith, taken together with the prevailing prices of the materials in question. For the best results with annual crops, to which our remarks particularly apply, sulfur in some form, probably as flowers of sulfur, will have to be employed to supplement the nitrogenous fertilizer unless sulfate of ammonia is used.

No mention is made here of the work of investigators in this country and in Europe which have testified to the value of sulfur as a soil amendment because they have no direct bearing on the subject of this paper.

SUMMARY

1. The superiority of sulfate of ammonia over other readily available nitrogenous fertilizers for barley on the Oakley blow sand as demonstrated in earlier experiments is confirmed in a new series of tests.

2. The cause of such superiority of sulfate of ammonia was sought for and believed to be found in its sulfur content.

3. A statement of the mode of procedure employed in the experiment, and also details of the results obtained and their discussion are submitted above.

REFERENCES

(1) Lipman, C. B., and Gericke, W. F. 1916 A vegetation experiment on the availability of nitrogenous fertilizers in an arid soil. *In* Soil Sci, v. 2, no. 6, p. 575–581.

(2) Lipman, C. B., and Gericke, W. F. 1917 Experiments on the effects of constituents of solid smelter wastes on barley growth in pot cultures. *In* Univ. Cal. Pub. Agr. Sci., v. 1, no. 13, p. 495–587.